RAILWAY TRACK

DESIGN, CONSTRUCTION, MAINTENANCE

AND

RENEWAL OF PERMANENT WAY

BY

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PREFACE

HE multiplicity of operations involved in the construction and aintenance of Railway Track or Permanent Way, requires from iose entrusted with these works, a thorough knowledge not only f the most efficient methods for modern loads and speeds, but so of the underlying principles of design.

Little has been written concerning the actual maintenance thods, particularly those not highly mechanised, and the author s therefore devoted a number of chapters to the discussion of is aspect of the subject.

The methods of construction, of renewal, and of improve-ent of track have been described in detail, and the measures o be adopted in emergencies have been explained.

The theory and practice of the intricate subject of Points and Crossings has been dealt with concisely in two chapters, and complete proofs have been given for all formulæ.

The manufacture, tests and treatment of materials used, and their capabilities and limitations, have been explained.

Subjects such as Signalling and Interlocking, and Bridge Maintenance, with which a trackman is intimately connected, have also been dealt with briefly.

Modern tendencies have been indicated in the discussion of every aspect of track work, and frequent comparisons have been made with track practice abroad, particularly in the United States of America, as the type there is similar to the Indian track.

The book is based on the notes taken by the author during several years of track experience, and has been undertaken, with the hope that it will serve, both as a text-book for those new to the subject, and as a reference manual for those well versed in the intricacies of Railway track.

This book is the direct outcome of discussions on the subject of suitable books on Railway track, by the *Bombay and Western India Branch* of the *Permanent Way Institution*, and is in no small measure due to the encouragement given by Mr. K. C. Bakhle, formerly Chief Commissioner of Indian Railways and Mr. W. R. Maunder, formerly General Manager of the Western Railway.

Opportunity has been taken in the publication of various editions to bring the text up-to-date through revisions. In this fifth edition, the book has been rearranged in six parts, enlarged

and modified. Track-vehicle reaction has been treated more comprehensively and various aspects of track stresses and train resistances have been covered.

A new concept of track structure resulting from the introduction of long welded rails supported by heavy sleepers with resilient soleplates and suitably consolidated ballast, needs to be appreciated, as it is considered a significant advance in permanent way in recent years. Details of requirements of such a track are incorporated in appropriate chapters.

The author wishes to acknowledge his indebtedness to the Railway Board, New Delhi, for permission to quote from the author's papers in *Quarterly Technical Bulletins*, to the General Manager of the Western Railway for the use of several photographs, to the publications of the Engineering Section of the *Indian Railway Conference Association* and of the *Track Standards Committee*, and to the *Schedule of Dimensions* issued by the Railway Board. He wishes to thank Dr. D. P. Antia, Major M. F. Mobedjina, and Messrs. N. M. Thadani, P. R. Mullan, J. S. Bhavra, S. N. Patwa, A. B. Walawalkar and F. N. Bharucha for assistance in various ways; Mrs. M. DeMello for help in typing, and his wife Amy and daughter Thrity for proof reading.

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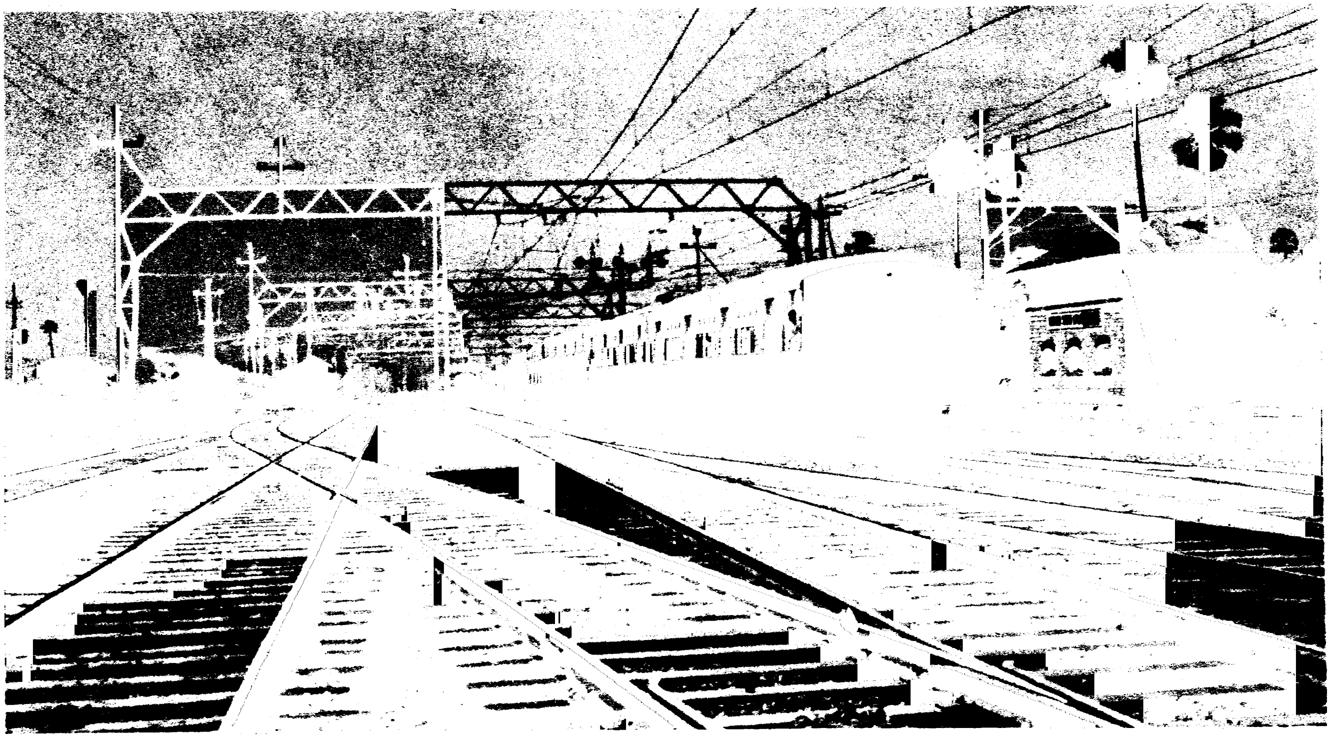
August 1960. *K. F. Antia.*

PART 1

Introduction and Materials

1. GENERAL
2. RAILS
3. SLEEPERS
4. FISHPLATES
5. TRACK FITTINGS
6. BALLAST AND FORMATION



Tracks to carry heavy suburban traffic. A turnout, a crossover and a diamond crossing are visible

CHAPTER 1

General

101. Early development

RAILWAYS or railroads are a development of "*Tramways*" and "*Plateways*" of the eighteenth century. The original tramways consisted of two lines of slabs of stones or baulks of timber laid flush with an existing road surface to facilitate haulage of heavy loads by horses. The timber baulks were subsequently covered with iron straps or plates to reduce wear. These plates were later replaced by angle irons with one edge vertical to keep the wheels on the track. These were known as plateways. In 1789 cast iron beams with supports at the ends were used by William Jessop in England and the present permanent way or track was gradually evolved.

The steam engine was developed after the introduction of tramways. Although experiments with steam carriages were carried out since 1771 by Niçolas Cugnot in France and later by William Murdock in Britain, the first locomotive to run on rails was built in 1802 by Richard Trevithick and sufficiently perfected in 1814 by George Stephenson to give practical results. The first railways

in England, America and India were the Stockton and Darlington (started in 1825), the Mohawk and Hudson (1833) and the Great Indian Peninsula (1853) respectively.

102. Description

The two rails of a track (Fig. 102) produce a most economical path for the smooth passage of heavily loaded vehicles at great speed. Sleepers or ties hold the two rails at the exact distance or gauge throughout and transfer the loads from the rails to the ballast. The ballast provides a resilient bed, keeps the sleepers in the correct position and at the correct level, distributes the load from the sleepers to a large area on the bed or formation of the track and drains off rain-water. The rails are fixed to the sleepers with various types of fittings which depend on the type of rail used, and on various other considerations. The rails which are manufactured in standard lengths are joined together with fishplates or joint bars through which fishbolts or track bolts are threaded.

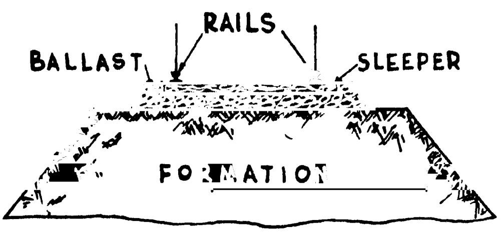


Fig. 102

103. Definition of track or permanent way

The combination of rails, sleepers, fittings, ballast, etc., is known as the track or permanent way. In some countries, temporary tracks were laid for conveyance of earth for the building up or the formation of a railway, and the permanent way was so called to distinguish the final layout from these temporary tracks.

104. Points and crossings

Special arrangements are necessary to transfer vehicles from one track to another track. The wheels of railway vehicles are provided with flanges to prevent them from running off the rails. With such wheels difficulties arise when the vehicles have to be moved from one track to another. Several methods are used for such transfers. Traversers, in which lengths of tracks are moved

sideways bodily with the vehicles on the movable tracks, are used in large workshops. This is however an expensive method, although economical in space, and cannot be adopted for general use. Another method is to revolve a small length of track so that the

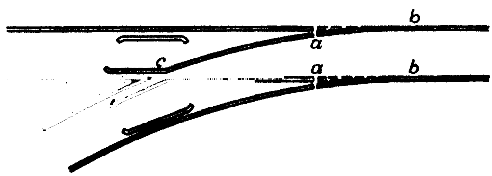


Fig. 104*a*

vehicle on the revolving track or turntable can be transferred to any of the tracks radiating from the turntable. Such a device is used for turning engines but is obviously out of question for full lengths of trains due to the enormous area required by the radiating lines and the difficulties of balancing a very long turntable. The simplest method of transfer is to interlace two or more tracks and leave small gaps in the rails at certain points to allow the wheel flanges to move across the rails. *Stub switches* (Fig. 104*a*) and crossings were originally used. In these, a break occurred in both rails of the principal track; short lengths *ab* in both rails were hinged at *b* and pulled over to be in line with either the principal or the subsidiary track. Where one rail of the principal track crossed another rail of the subsidiary track a short piece of rail was pivoted near the centre (not shown in Fig.104*a*) and turned to correspond with either of the two tracks as required. As stub switches and crossings have no lateral support and are much too weak for modern speeds and loads, they are used only for temporary construction tracks.

The type of points and crossings almost universally used is shown in Fig. 104*b*. One rail AB of the principal track and one rail CD of the subsidiary track are continuous and the opposite rails EF and GH of both the tracks are fixed upto the points J and K. The lengths JH and KF are tapered towards H and F, are connected together with rods near the tapered ends, are hinged at J and K and can move radially through a short distance with J and K as centres so that when JH butts against AB as shown in the figure, a vehicle moving in the direction BA is diverted to BG. When KF butts against CD, JH is pulled away from AB and a vehicle travelling along the straight track continues in the same direction over the points. Where the rail HG crosses the rail FE at point T the rails are splayed out to form wings and a V-shaped piece

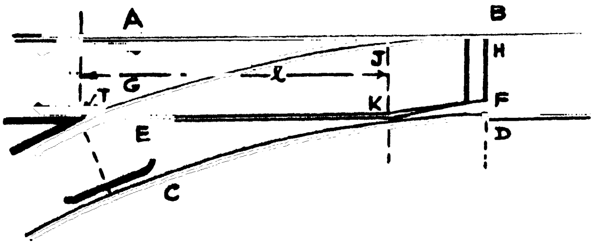


Fig. 104*b*

is provided. This allows spaces for the flanges of wheels for crossing either the rail HG or FE. Guard rails are provided opposite the V to guide the wheel flanges of the opposite wheels through the spaces on either side of the V.

105. Gauge of track

A railway track is required to bear very heavy loads and to permit such loads to move in safety at high speed. In order to achieve this economically, certain standards of loads, of speeds and of gauges have been established.

The gauge to which the first railway track was laid was 4′-8½″ and by far the greatest mileage of the railways of the world are laid to this gauge. The reason for this particular dimension lies in the plateways of the eighteenth century. The angle iron plateways mentioned in para 101 were fixed 5′ apart. When rails were introduced, wheels were provided with flanges on the outside of the rails and the gauge still remained 5′. Later the flanges of wheels were fixed on the inside of rails and the same 5′ gauge then became 4′-8½″ due to the deduction of the width of 1¾″ of each rail. In America and many other countries the same gauge was adopted. In India the first railways were laid to a 5′-6″ gauge.

106. Different gauges

It must be remembered that the cost of construction of a railway increases with the gauge, although the carrying capacity and the permissible maximum speed also increase at the same time. The choice of gauge depends very much on the amount or density of traffic expected, on various economic factors, and on the physical

features of the country. When additional tracks are built in a country or area already provided with railways, an additional and a most important factor, namely the recurring cost of transferring passengers and goods from one gauge to another has to be considered. If the amount of money available is insufficient for a railway of 5′-6″ gauge, it is advantageous to build a railway to a smaller gauge for which the available sum would suffice rather than build no railway at all. Again if the trade and industries of a certain area are not likely to produce sufficient traffic to use fully the carrying capacity of 5′-6″ gauge railway, such a railway is likely to work at a loss, whereas a smaller gauge railway might be run profitably. Economic factors were the cause of the introduction of the 3′-3⅜″ or metre gauge in India in 1871. For developing poor areas and for bringing merchandise to the main railways, gauges even narrower than the metre gauge are used. Such railways with 2′-6″ and 2′-0″ gauges are sometimes termed "*Feeder*" railways. Again, if the country is mountainous, the cost of a railway of 5′-6″ gauge might be prohibitive due to the larger quantities of earthwork, heavier bridges, larger tunnels, flatter gradients and curves of larger radii, whereas a smaller gauge railway might be quite feasible. Examples of these are found in the 2′-6″ narrow gauge railways to the various health resorts situated on the hills in India.

One of the most important factors is however the transfer of passengers and goods at the junction of two railways of different gauges. Considerable delays to movement of traffic and additional expense occur due to a break in gauge and this is a serious hindrance to trade. The problem is of such importance that serious controversies have taken place in India, in Britain and in other countries and some railways have had to alter their gauge to conform with that of the neighbouring railways; the largest conversions took place in America and Canada. In England the 7′-0″ gauge of the Great Western Railway had to be converted to 4′-8½″.

At present well over half the railways of the world are laid to 4′-8½″ gauge, whilst the metre and 5′-6″ gauges cover almost one-eighth and one-thirteenth of the total mileage respectively. The distribution in India is 50% broad or 5′-6″ gauge, 40% metre and 10% narrow gauge. The gauges adopted in various countries are shown in Appendix 13.

107. Speed

Speed is an important factor particularly with trains covering long distances or connecting two or more important commercial, industrial or administrative centres. As a general rule, the wider

the gauge the greater is the speed possible consistent with safety. For instance, the speed of trains on South African railways of 3′-6″ gauge does not exceed 50 miles per hour whereas on the 4′-8½″ gauge, speeds of over 90 miles per hour are not unusual. Top speeds of 110 miles per hour with the record standing at 125 miles per hour with steam locomotives have been attained on the 4′-8½″ gauge. A speed of 205 m.p.h. with an electric locomotive was attained in France in 1955. Gauge is however not the only factor in governing the maximum speeds. The strength of permanent way, power of locomotives, weight of trains, nature of formation under the track, sharpness of curves, steepness of gradients, standard of maintenance and numerous other factors, including economic factors, govern the question of speed. The speed on the 5′-6″ broad gauge in India is limited to 60 to 65 miles per hour (and on the metre gauge to 45 miles per hour) whilst higher speeds on the smaller 4′-8½″ gauge are permitted in Britain and America.

108. Axle loads and hauling capacity of locomotives

The capacity of a locomotive to pull loads is specified by its *tractive effort* which depends on various factors in its design. The tractive effort has to be adequate to overcome various resistances. These resistances depend upon the axle friction of both the locomotive and the vehicles behind it, the atmospheric resistance (i.e. the resistance encountered from the atmosphere by any object moving at speed), the wave action of the rails, track irregularities, the gradients in the track, the sharpness of curves, wind resistance and the resistance at starting and at accelerating.

The hauling capacity of a locomotive, namely the train loads which it can pull, is also governed by the adhesive force which depends on the weight on its driving wheels and on the coefficient of friction between the wheels and the rails. This coefficient varies between 1/4th and 1/6th depending on the condition of the rails, namely dry, wet, etc. The coefficient may be even less with greasy rails. The hauling capacity of a locomotive may therefore be taken very roughly as 1/4th to 1/6th of the load on its driving wheels. A locomotive is incapable of hauling any loads beyond this value. The adhesive force is therefore the governing factor in determining the hauling capacity of a locomotive. It is evident from the above that the axle load of the driving wheels of engines is an important factor and standards for these have been laid down in all countries. In India, the maximum axle load is 28 tons for the broad gauge, the corresponding figures for the metre and narrow gauges being 17 tons and 13 tons respectively. America has the heaviest axle

loads reaching over 35½ tons whilst the maximum in Britain is just under 23 tons. The weight of the diesel electric locomotives, which are used in greater numbers than steam locomotives in America, is 26 tons. It may be noted that with a restricted axle load, the hauling capacity of a locomotive may be increased by having more driving wheels, provided the weight and power of the locomotive are also increased. The weights of the heaviest locomotives in India are just over 200 tons, in America nearly 450 tons and in Britain about 160 tons.

By far the greater portion of the track in India is designed for 22½-ton axle load for broad gauge track, and 13-ton axle load for metre gauge track.

109. Gradients

When a train moves along a rising slope or gradient, the locomotive has to exert a greater pull, the additional force necessary is the same as that which would be required to lift the train up the height through which it rises in every foot it traverses. For example, if a train weighing 500 tons travels over a slope rising 1 foot in every 150 feet, the additional force required is $\frac{1}{150} \times 500$ tons. If the same height 1 foot is attained in 400 feet the additional force required is only $\frac{1}{400} \times 500$ tons. Steep gradients necessitate more powerful locomotives, smaller train loads, lower speeds and costly haulage. It is therefore desirable to climb a slope at as gentle a rate as possible. As a rule *rising gradients* are followed by *falling gradients*. On the falling gradient the weight of the train is an advantage to its progress. The amount of energy which was used up in climbing is, so to say, returned in descending. Also if trains travel in either direction over the same track, a rising gradient in one direction becomes a falling gradient in the opposite direction. A train is able to climb a rising gradient more easily if this rising gradient follows a falling gradient as the train has an opportunity of attaining high speed over the falling gradient before reaching the rising gradient.

If a track rises 1 foot in 100 feet the gradient is called 1 in 100 or 1 per cent gradient. A rise of 1′ in 200′ is therefore equivalent to a 1 in 200 or ½ per cent gradient. For each length of railway, the steepest slope at which a track is laid is fixed and is known as the *ruling gradient*. A ruling grade is so called because it limits the maximum weight of a train which can be hauled over the section by a locomotive. Ruling gradients of 1 in 200 to 1 in 100 are not uncommon for broad gauge tracks in India. In Britain a 1 in 100 gradient is considered steep whilst a 1 in 300 gradient is

regarded as easy. Much steeper gradients than these have to be provided in mountainous regions. Where they become so steep as to necessitate the help of an extra engine, such grades are called *pusher grades.* Examples of these exist in the Western Ghats in India. As steep gradients curtail the train loads which can be hauled over them, they are uneconomic and if an extra engine has to be used, the cost is further increased. Loops and spirals are often formed in a track in difficult country in order to keep the gradient as small as possible.

The grades in station yards have to be sufficiently low in order that (*a*) vehicles left standing on the tracks do not start moving automatically due to the effect of gravity combined with a strong wind and or a gentle push, and (*b*) locomotives, which have at starting to overcome a resistance which is twice as much as when they are already on the move, are not encumbered with a further resistance due to grade. On Indian railways, for all gauges, the maximum gradient permitted in station yards is 1 in 400 whilst a gradient of 1 in 1000 is recommended. Further details are given in para 910.

110. Curves

Although it is desirable to lay a track which is as straight and has as gentle a gradient as possible, it is not possible to do so in almost all cases due to the natural features of the country and due to the necessity of avoiding obstructions both natural and artificial. As curves are unavoidable, it is desirable to make them as flat, namely of as large a radius, as possible. The reason is that curves introduce further resistance to the haulage of trains, produce considerable wear both in the track and in the vehicles, reduce the safe limit of speed, and increase maintenance costs.

It is more convenient to define the sharpness of a curve by the degree of curvature than by its radius. The degree of curvature is the angle D (Fig. 110) subtended by an arc AB of length 100′ of the curve. The radius of 1 degree curve is 5730′ and the radius of any degree of curve is obtained by dividing 5730 by the degree. The radius of a 3° curve, for instance, is $\frac{5730}{3} = 1910'$. The radii for various degrees of curves are given in Appendix 10. The maximum degrees of curvature permitted in India are 10° for broad gauge, 16° for metre gauge and 40° for narrow gauge. In America though no definite limit has been laid down, a 10° curve on a 4′-8½″

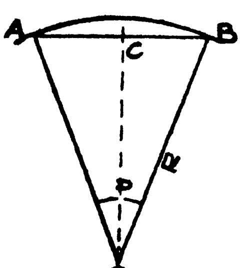


Fig. 110

gauge track is not usually exceeded. In a few cases however very much sharper curves exist. With sharp curves the speed is severely restricted, the restriction in the case of broad gauge with 10° curve being 28 miles per hour. Curves of more than 3° on the main broad gauge tracks should be avoided. The permissible speeds for any degree of curve can be obtained from the formula

$$V=1.5\sqrt{\frac{5730}{D}-220} \text{ for broad and metre gauges}$$

$$\text{and } V=1.25\sqrt{\frac{5730}{D}-20} \text{ for narrow gauge}$$

where V=permissible speed in miles per hour and D=degree of curvature. Even these maximum speeds are only permitted if the ends of the curves are connected to the straight tracks by special curves called *transition* or *easement curves*. If these special curves are omitted, speed is further reduced to 4/5ths of the above values. Not only is the speed reduced due to curvature but the locomotive has to exert a greater power in order to overcome increased frictional resistance due to centrifugal force and sliding (*vide* para 210). If a sharp curve happened to be situated on a rising gradient (para 109) a locomotive may be able to pull the train at a very low speed or not at all. Hence, when a steep curve is to be laid, the gradient is kept smaller than the ruling gradient and the amount by which it is reduced is known as *compensation for curvature*. The practice in America is to allow .03% to .05% (i.e. 1 in 3333 to 1 in 2000) compensation for every degree of curvature in the curve. For instance if a 3° curve is located on a ruling gradient of 1 in 150 or 0.67%, the gradient is reduced to $0.67-(3\times.05)=.52\%$ or 1 in 192 on the length of the curve.

111. Modern tendencies

As a result of increasing competition from other forms of transport, considerable attention is being given by railways to increased comfort and efficiency coupled with increased economy.

Higher speeds, streamlined air-conditioned vehicles, and fast lightweight vehicles have catered for greater comfort. More intense use of locomotives and vehicles, centralized control of train movements and increased capacities of trains with more powerful locomotives have led to greater efficiency and economy. These tendencies, particularly higher speeds and high-powered locomotives, in turn, have made great demands on the permanent way, as the speed of trains depends on the strength and condition of the track. Research continues on track-vehicle relation. Rail joints are being eliminated through welding of rails. Worn rails and points and

crossings are renewed by welding; sharp curves in tracks are eliminated by diverting the track, sometimes at great expense to produce smoother curves; steep gradients are being replaced by flatter ones, again by diverting the track or by tunnelling through hills. Increased use is made of mechanical devices in maintaining the track; maintenance men are given longer lengths of tracks with greater mobility and are specialised in the various types of maintenance work. The axle load of vehicles is being reduced by improved designs (e.g. stressed skin design), welded construction and use of light alloys, such as aluminium.

Diesel power has almost completely replaced steam locomotion in America and other countries.

Giant gas turbine locomotives have also been introduced and investigations on atomic-powered locomotives are on hand.

Signal lamps have been developed which use radio-active isotopes and stay bright for 12 years.

Low slung lightweight rail cars which can move at 100 miles per hour are being tried, and goods wagons are being introduced for special requirements such as for fragile products, for bulk transport of products in powder or grain form, and for oversize consignments.

Electronic control of train movements has been introduced in America, in which over 160 miles of track are controlled from one place. This together with other arrangements has resulted in two tracks being able to handle traffic for which four tracks were formerly required.

The introduction of electronic devices in the marshalling of wagons has resulted in the handling of 9,000 wagons per day from one place.

112. Standard dimensions

In order that (*a*) vehicles of one railway may travel with safety on any other railway of the same gauge, (*b*) no structure may be dangerously close to or in the way of a moving vehicle, and (*c*) passengers may not be injured on account of insufficient clearance between moving vehicles and fixed structures, certain dimensions for railways are prescribed in each country. The standard dimensions in India not only specify the maximum sizes of vehicles, and the minimum clearances required for safety but also give the degree of the sharpest curve, the weight of rails for specified axle loads, the permissible speeds on curves, the maximum gradients in

yards, the size and number of sleepers to be used, recommendations for improved standards, and infringements which may be permitted in certain circumstances. In Appendix 12 are given a set of selected dimensions for broad, metre and narrow gauges as prescribed by the Railway Board in India.

113. Loading gauge

The loading gauge represents the maximum width and height to which a vehicle may be built or loaded. Bridges, tunnels and other structures are built so that the sides and top remain clear of the loading gauge. The construction gauge is obtained by adding necessary clearances to the loading gauge. The loading gauge has a considerable bearing on the carrying capacity of track as the dimensions of vehicles are restricted to this gauge. In Britain, the maximum height to which a locomotive or vehicle can be built is 13′-6″ whilst in Europe it is 14′-0″ and in America 16′-0″, all using the same track gauge of 4′-8½″. The width permitted in Britain is 9′-6″ and in Europe 10′-2″. With 5′-6″ track gauge in India, the height and width recommendations are 15′-6″ and 12′ respectively; for metre gauge, the dimensions permitted are 11′-3″ and 8′-6″. The possible increase in the carrying capacity of a vehicle and the hauling capacity of a locomotive with a loading gauge of 15′-6″ × 12′ over that of 13′-6″ × 9′-6″ are considerable.

CHAPTER 2

Rails

201. General

In Chapter 1 the functions of a rail have been indicated. The original rails were made of I or dumb-bell section (Fig. 201*a*), the idea being that when the top table or head of this doubled-headed rail was worn, the rail could be inverted and re-used. Such rails

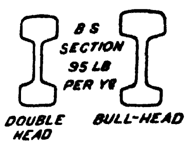


Fig. 201*a*

are supported in chairs which rest on sleepers. It was found that the lower table was dented by the chairs and could not be used. This led to the development of the bull-headed rail with a similar shape but with more metal added to the head to permit wear. The lower table was made of just sufficient size to be able to bear the stresses which are induced in it by moving loads.

Side by side with the development of the double-headed and bull-headed rails, a flat-footed rail, which is of an inverted T shape (Fig. 201*b*), was introduced. The advantage of these rails, also called Vignole rails from its original designer, lies in the fact that for the same weight, flat-footed rails are stronger than bull-headed rails; also no chairs are necessary and the foot of the rail may be spiked direct to the sleepers. On the other hand, it is claimed for the bull-headed rail that it gives a more solid and smoother track, and that the advantages of elimination of the chairs is offset by the necessity of using bearing plates under flat-footed rails to distribute heavy loads on sleepers made from soft wood. Following are a few more points in favour of each type.

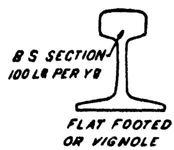


Fig. 201*b*

(*a*) The B. H. rail keeps better alignment of track than the F.F. rail.

(*b*) F.F. rails are cheaper than B.H. rails.

(*c*) F.F. rails, as such, have more lateral or side strength than B.H. rails. Recent research on lateral strength of tracks has however shown that the lateral strength of track structure as a whole is not appreciably affected by the type of rail used.

(*d*) F.F. rails require fewer fastenings than B.H. rails.

(*e*) The fastenings with F.F. rails have a tendency greater than the B.H. rails to get loose, particularly if they are laid on wooden sleepers. The wave effect in the rails tends to loosen the spikes with which the rail is held to the sleepers.

By far the largest mileage, nearly 90%, of railway track in the world, is laid with flat-footed rails. Various other types of rails have been designed but as their use has been very small, they need not be considered here.

202. Weight and section of rail and their relation to axle load

A rail is defined by its weight per yard and a 90-lb. rail is a rail which weighs 90 lbs. for every 3′ of its length. The weight of a rail is governed by the heaviest axle load which it is expected to support. On 4′-8½″ gauge, the approximate axle load which can be carried by a rail is taken (in America) as 300 times the weight of the rail per yard. Several other factors have to be considered in determining the weight of the rail, including the maximum speed and the spacing of sleepers. As a rule, on 5′-6″ gauge, a rail may be expected to carry an axle load 560 times the weight of the rail per yard. For instance, a 90-lb. rail can bear an axle load of roughly 90×560 lbs. or 22½ tons. It may be pointed out that although it is possible to increase the strength of a track, namely increase the axle load which may be permitted on it, by increasing the number of sleepers, such an increase is very small and it is more economical to replace light rails with heavier rails. Moreover, with rails having the same profile, the cost varies as the depth whilst the strength varies as the square of the depth. In order to cope with the increased loads considerable relaying has been carried out in all countries within recent years. Whereas 75-lb. rails were in general use in India about 40 years ago, 90-lb. rails are common today and 100-lb. B.H. and 115-lb. F.F. rails have also been used. In America, in the same period, the weight of rails has been increased from 100 lbs. to 130 lbs. and has reached a maximum of 152 lbs. In Britain, 95-lb. to 100-lb. rails are used.

The results of a 10-year investigation by the American Railway Engineering Association concluded in 1954 have brought out forcibly the savings both in capital cost and in maintenance through the use of heavier rails. Comparison between 20-mile lengths of 112-lb. and 131-lb. rails under identical traffic showed a saving of 6.6 per cent in investment cost and 13.4 per cent in maintenance cost with 131-lb. rail over the lighter 112-lb. rail. The savings in sleeper renewals were 56.9 per cent and in ballast renewals 23.3 per cent. Moreover, 12 out of 20 miles of the 112-lb. track had been renewed within 10 years whereas no renewals were necessary with the 131-lb. rail.

The following is yet another advantage of a heavier rail as compared with a light rail. When a loaded wheel moves over a rail, it depresses the rail and if the rail is light compared with the load it has to bear, the greater is the depression. The wheel has continually to be dragged out of such depressions and the result may be compared to that of dragging a cart in sand. The waste of power is obvious.

The sections of rails are standardised in most countries. Some of the sections standardised in India by the Railway Board and in America by the American Railway Engineers' Association and other allied associations, are given in Appendix 1. The axle load permitted on each section of rail is given in Appendix 12, item 21. It will be noticed that there is very little difference between the Indian and American standards. The axle loads shown against the various sections are permitted provided the wear of rail does not exceed 5%.

A modified section of flat-footed rail has also been developed in America and is known as *Head Free rail* (Fig. 202). It is so called because the fishplates do not support the head of the rail as with standard fishplates but are in contact with the rail along the curve of the head fillet. The advantages claimed for such a rail are that the unnecessary material at the bottom corners of the head are removed and used on the top of the head, thus giving more material for wear by wheels and also strengthening the rail.

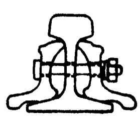


Fig. 202

203. Length of rail

The length of rails vary considerably in various countries. As the rail joint is the weakest part of a track structure, its strength being about one half that of the rails, it would appear to be desirable to use as long a rail as possible. Wear and tear of vehicles is decreased and comfort of passengers is increased by longer rails, as the number of blows experienced at the joints by a moving vehicle are diminished. The length of a rail is however governed by the length which can be produced at a reasonable cost by the manufacturers. A further limiting factor is the transport of rails. Rails have to be of such lengths that they may be carried in the longest standard wagons. Very long lengths of rails have been transported but a series of special wagons are required for such a feat with resultant increased cost. Again, very long rails cannot be handled by manual labour and special handling devices, such as cranes, are necessary. Also if a defect is found in a rail, a much longer length has to be wasted in renewal than in the case of short rails.

Steel expands with heat and contracts with cold, the amount of such variation for every 42′ length of rail being 1/6″ for every 50°F. difference in temperature, as the expansion for every 1° rise per 1′ length of rail is .000078″. An expansion gap is provided at the end of each rail. Theoretically the longer the rail, the larger

is the expansion gap. This however is not the case in practice as explained in para 204, and the expansion gap is not now considered to be one of the factors controlling the length of rails.

Rails varying in length from 20′ to 42′ are in use in India, the standard lengths being 42′ for B.G. and 39′ for M.G. The length of 42′ has been selected, although a 60′ length was considered desirable, as the length of the longest wagons is 45′. It was reckoned that the extra cost of manufacturing 42′ rails as compared to the old standard of 36′ rails would be more than compensated by the saving in the number of sleepers and joints with longer rails. In America, the normal rail length is 39′. In Britain, the standard length is 60′ whilst lengths of 90′ are not uncommon and 120′ rails have also been used. In Britain, the economic limit of length is considered at present to be 90′. The standard length of rails on main lines in Germany is 98′-5″ (30 metres) and considerable numbers of rails of 78′-9″ (24 metres) are in use in France.

Although no limit has been prescribed for the shortest piece of rail which may be used in a track where there is through traffic, it is desirable not to have any piece of rail which is shorter than the largest rigid wheel base of wagons, namely the distance between two adjacent axles. The distance between bogies of a vehicle does not affect the minimum length of rail. The wheel base for wagons in India is 12′, hence pieces of rail less than 12′ long should not be used in through tracks.

204. Lengthening rails by welding

The advantages of fewer joints are so great that the practice of joining the rails together by-welding is on the increase. Welding the ends of adjacent rails overcomes many of the disadvantages of long rails, particularly those of manufacturing and handling. The rails are welded together after laying by one of a number of methods. Rails have been welded in lengths of over a mile. The expansion gap, if worked out for this length as given in para 203, would be very large but it has been found in practice that very long rails do not expand much more than the normal 42′ rails. The reason is that the fittings which hold the rails to the sleepers prevent large movements. On the other hand, considerable stresses are introduced in the rail by prevention of expansion. This however need not be considered as affecting the strength of the track as the joint has a strength, as already stated, of about 50% of the rail. One danger however has to be guarded against with very long rails. When the two rails of a track are under considerable stress due to expansion, they may force the track sideways and cause

side bulges, known as buckles, in the track. A buckle would derail a train with serious consequences. Hence unless the lateral strength of a track is adequate, it is unwise to increase the length of rails indefinitely by welding.

An experiment is being conducted by an Amercian railway with "Frozen" rail joints. This consists in laying rails with the ends butting tightly one against another and without any space for expansion. The object is the same as that of welded rails, namely elimination of joint maintenance. Frozen joints, if successful, would however avoid the cost of welding and of handling long welded rails and enable easier replacement in case of damage.

205. Strength of rail steel

Steel used in rails is stronger than that ordinarily used in structures and has an ultimate stress of from 44 to 55 tons per square inch, namely, it will break only when a pull of 44 to 55 tons is exerted on one square inch of section. For safety purposes and for various other reasons such as fatigue, a stress however of not more than 45% of the ultimate stress is permitted.

206. Coning of wheels and its bearing on rails

The tread or rim of wheels of railway vehicles are not made flat but are sloped and this sloping surface along the circumference forms part of a cone (Fig. 206). On a straight and level track, the wheels remain central and the circumference of the treads of both wheels are equal. When travelling round a curve, the outer wheel has to move over a greater length than the inner wheel. As the vehicle on a curve has a tendency to move sideways towards the outer rail, the circumference of the tread on the outer rail becomes greater than that on the inner rail and this helps the outer rail to cover a greater distance than the inner rail. This condition however holds good when two or more axles are not connected together by the rigid frame of a vehicle. When the wheels are so connected, and this is the normal condition, the trailing or rear axle has a tendency to move towards the inner rail due to the rigidity of the frame and full advantage cannot be taken of coned wheels. Wheels are however coned to maintain the vehicle in a central position with respect to the track. Due to slight unavoidable irregularities in a resilient track, the wheels move very slightly from side to side

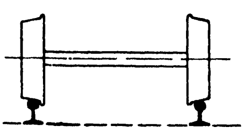


Fig. 206

due to the slight swaying of the vehicle. If there was no coning, this movement would often continue till the flange came in contact with the side of the rail tread and a sudden slight shock would be the result. Due to coning of wheels, this side movement results in the tread circumference of one wheel being increased. This induces the wheel to slide and due to resistance on account of sliding, further side movement is stopped before the flange comes in contact with the side of the rail head. Coning of wheels therefore produces smoother riding, but it also wears out the rail quickly, as the pressure of wheel is near the inner edge of the rail. Lateral bending stresses are also set up in the rail. This same pressure is also concentrated on the outer edge of the foot of the rail. Sleepers are therefore also liable to damage due to the load not being uniformly distributed along the full width of the rail foot. To reduce this wear and the lateral stresses, rails are not laid flat, but are tilted inwards at a slope of 1 in 20 which is the slope of the wheel cone. Tilting of rails is the standard practice in India and Britain but has not been universal in America, although the majority of railways there adopt this measure. Tilts of 1 in 40 and even 1 in 80 have sometimes been adopted there, but the standard practice now is a tilt of 1 in 20. For other reasons, rails in switches and crossings and on the length of track between them are not tilted.

207. Bending of rails

When a rail is laid on a curve, unless the rail is bent to the curvature of the curve, elbows occur at the joints, as the joint is less flexible in the horizontal direction than the remaining portion of the rail. With flat curves, namely those of less than 3°, the rails when laid are retained in the curved position by the sleepers which, in turn, are held by the ballast heaped up at their ends,

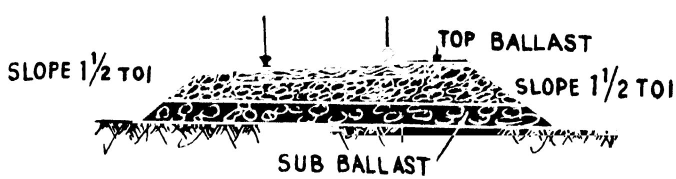


Fig. 207*a*

such heaping up of ballast, usually flush with the top of sleepers (Fig. 207*a*), is known as *boxing*. With curves sharper than 3°, it is desirable to bend the rails to the correct curvature before fixing

them to the sleepers. This, unfortunately, is not always done and the side thrust on the ballast at the ends of sleepers, due to the rail which behaves like a horizontal spring in this condition, is sufficient to form elbows at the joints and disturb the alignment or correct position of the track.

The amount, by which the rail is to be bent, can be found very simply. In Fig. 207*b*, ADB is an arc l of a curve with radius DE $= r$ and centre E. AB is a chord of length $2c$ and versine CD $= v$. It may be proved that $v=\frac{c}{2r}$ approximately. This relation is accurate enough when the arc l or length of rail is small compared to the radius of the curve. In such cases, an arc ADB is also considered nearly equal to the chord ACB. The rail has therefore to be bent so that the correct versine according to this formula is obtained. For example, if a 42′ rail is to be laid on a 6° curve, the rail is to be bent so that its

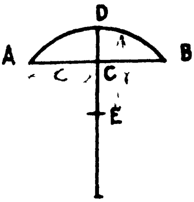


Fig. 207*b*

$$\text{versine}=\frac{21^2}{2\times5730/6}=0.231'=2.77''$$

since $c=$AC or AD$=\frac{l}{2}$ and the radius of 6° curve$=\frac{5730'}{6}$.

Rails are bent on curves of over 4° on many railways in America.

208. Cutting of rails on curves

Rails are usually laid with the joints in the two parallel rails exactly opposite to each other. When the track goes round a curve, the outer rail has to describe a larger circumference than the inner rail. The result is that joints on the outer rail gradually fall behind those on the inner rail. When the difference is equal to that between the two bolt holes in the rail (generally 4½″), a piece, double this length, is cut off from one inner rail. The joint on the inner rail thus falls back by 4½″ and after a certain number of rail lengths, the joints come exactly opposite to each other. Recent practice is not to have the joints opposite to each other on curves, but to stagger them by half a rail length or a shorter distance. This averts elbows and produces better running.

209. Widening gauge on curves

The gauge of track on sharp curves is sometimes found to spread, namely to become larger than the correct gauge, after a number of vehicles have moved over such curves. Sometimes, the

rails are also found to tilt outwards. The reason for the spread of gauge and outward tilt is the rigidity of the wheel base. The wheel base of a vehicle is the distance between two adjoining axles held in a rigid frame. The maximum wheel base in India, for broad gauge, is 20′. When going round a curve, the axles take up a position shown in Fig. 209. The outer wheel of the front axle F butts against the outer rail and the rear axle R takes up a position so that it is in line with the radius of the curve. When curves are so sharp as to prevent the rear axle from taking up this position (the wheel base being the same), the rails are thrust or tilted outwards. To prevent this, the gauge is widened on sharp curves. If the gauge is widened more than the correct amount, the outer wheel of the front axle has a greater tendency to butt against or bite into the outer rail and this causes greater wear of rail.

The amount, by which the gauge should be widened, is obtained by simple calculations based on the following observation. It has been found that the outer rear wheel stands away from the outer rail by a distance CD (Fig. 209) and this distance is the versine of a chord of which the length is twice the wheel base. From the relation given in para 207, the radius or degree of a curve at which widening is necessary is obtained. In this connection, it should be remembered that the distance between the rubbing faces of the flanges of the two wheels is less than the gauge of the track. It was formerly the practice to widen the gauge on curves of over 3° on broad gauge, the amount of widening varying from $\frac{1}{4}''$ to $\frac{3}{4}''$ according to the sharpness of the curve. The present practice is not to widen the gauge on curves under $4\frac{1}{2}°$ as experiments have proved that widening is unnecessary on flatter curves. The practice on metre gauge varies; some railways do not widen the gauge upto 9° whilst others start widening at 5°. In America the practice is not to widen the $4'$-$8\frac{1}{2}''$ gauge up to 8°, then to widen it at the rate of $\frac{1}{8}''$ for every 2° of curvature upto a maximum of $\frac{3}{4}''$.

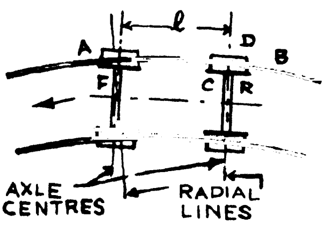


Fig. 209

210. Wear of rail—types

Wear of rails may be divided into three classes in accordance with the position of wear, namely (*a*) wear on top or head of rail, (*b*) wear at ends of rails, and (*c*) wear on the sides of the head. A head of a rail becomes worn due to the abrasion of the rolling

wheels over the rails, but wear on account of abrasion is insignificant when compared with that due to heavy wheel loads. The load of a wheel is concentrated on an extremely small surface on the rail and if the load is heavy enough, the stress in the rail exceeds the elastic limit and the metal in the rail stretches or "flows." Elastic limit may be roughly defined as the pull in tons or pounds, exerted on a section of one square inch of metal, which is just sufficient to stretch the metal. "Flow" of metal occurs only on the top of the rail and the rail assumes the shape shown in Fig. 210*a*. The projections of metal, shown in the figure beyond the original rail section, are known as *burrs*. When rails are burred, care must be taken whilst checking the gauge, not to measure the distance between the burrs. The head of a rail also gets battered and chipped due to the recurring impact of heavy loads. The wear on the head depends also on the weather; in rainy weather, the rails are lubricated by rain water and wear is diminished. In dry areas, where sand or dust constantly blows, extra wear occurs due to the grinding action of the sand or dust particles between the rails and wheels. Corrosion of rails on tracks adjoining the sea and corrosion due to the action of acids contained in the refuse falling from trains (particularly noticeable on tracks adjoining platforms), reduce the section of rails. When brakes are applied to stop trains, further wear occurs and if any sliding of wheels takes place, the metal in the rail head is burnt. Such burning is very pronounced if locomotives, when starting, are not able to exert sufficient pull to move the train instantaneously and, as a result, the driving wheels slip on the rails (*vide* para 108). Wear is increased by any looseness between rails and sleepers and also due to loose packing of ballast underneath sleepers. Observations in India have shown that on a busy through track, the rail wears at the rate of 1 lb. per yard per 10 million tons of load carried. Wear in America has been found to be $\frac{1}{2}$ lb. per yard per 10 million tons on a number of experimental rails. It has been computed in America that on a well maintained track, when approximately 200 million tons of load have passed over a 90-lb. rail, the wear reaches such proportions that the rail needs to be renewed. With 152-lb. rails, the corresponding figure is 550 million tons. As a rule, a rail, laid on a straight track, requires to be changed not so much on account of the wear on its head but due to wear at its ends. The gradient of a track also affects the wear of rail considerably, especially when combined with sharp curves, as is generally the case.

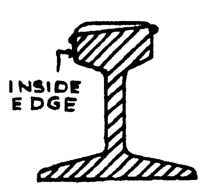


Fig. 210*a*

The second type of wear occurs at the ends of rails and is very much greater than the wear on the head of rails. This wear is primarily due to the blow which the end of a rail receives when a wheel jumps the gap between the rail ends. The ends of rails are battered by such blows; the surfaces of contact between rails and sleepers are worn and the effect of blows is thereby increased; the ballast under the sleepers at joints is loosened and this again increases the blow due to the sleepers being depressed under the blows. Fishbolts also get loose under constant impact and further increase the effect of blows. The result of all these causes is that the rail is not only battered, but is bent vertically at the ends; the metal also begins to flow towards the gap and this projecting metal subsequently gets chipped off.

The third and the most destructive type of wear occurs where tracks are laid on curves. When a vehicle moves round a curved track, it has a tendency to move sideways towards the outside of the curve due to centrifugal force. If flanges were not provided, the wheels would move off the rails on curves. This tendency is counteracted, as will be explained in a later chapter, by raising the level of the outer rail a little above that of the inner rail of the curve. The thrust of the wheel flanges against the side of the outer rail head results in the grinding of the rail by the flanges and side wear occurs on the outer rail. Also, as vehicles do not bend to the curvature when moving over a curve, the wheel flanges have a tendency to "bite" into the side of the outer rail head (*vide* Fig. 210*b*) producing still further wear. Wear occurs also on the inner rail of a curve. In railway vehicles the wheels are rigidly connected to their axles. When moving round a curve, the outer wheel has to move through a greater distance than the inner wheel, but as the two wheels cover the same distance, due to their rigid connection, the inner wheel has to slide over the inner rail. Such sliding causes great wear on the rail. This difficulty is overcome in motor cars by a mechanism known as a differential gear, but such a mechanism would be most expensive to install and maintain in railway vehicles. It will also be explained later that the amount by which the outer rail on a curve is raised above the inner rail, or the superelevation, varies with the speed of the train. Now it is obvious that it is not possible nor desirable to arrange for all trains to run over a curve at one fixed speed, nor is it possible to change the superelevation for varying speeds of different trains. The result is that some trains move at speeds which are greater than the speed, known as *equilibrium speed*, for

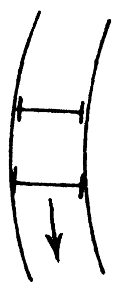


Fig. 210*b*

which the track is superelevated, whilst other trains travel at lower speeds. In the first case, the thrust of the flange of the outer wheel increases and the wear due to the grinding is considerably increased on the gauge side of the outer rail head. In the second case, the load of the vehicle instead of being equally divided over the two rails is considerably increased on the inner rail and diminished on the outer rail. The top of the inner rail is consequently considerably worn, and as stresses far in excess of those allowed for are often induced, it is not uncommon to see metal "flowing" on the head of the inner rail. Yet another reason for wear of the inner rail on a curve, is that the sleepers have to be laid at a transverse slope in order to give the necessary superelevation. When the rail is laid at a tilt of 1 in 20 on this sloping sleeper, the resulting tilt is different to the slope of the cone and produces wear as explained in para 206.

With the increased substitution of diesel electric for steam locomotives, the wear of rails on curves has been found to have increased. Four reasons are ascribed for the increased wear : (i) smaller diameter of driving wheel, (ii) lower centre of gravity of the locos, (iii) approximately uniform axle loads. This results in the elimination of the light front axle of the steam loco leading the heavier following axles, (iv) the tendency of diesel electric and electric motors to induce the wheel flanges to press more against the rails resulting in increased centrifugal force. A remedy suggested against increased rail wear is the introduction of rail and wheel flange lubricators.

It has been observed that the wear of rails on curves is higher on electrified sections particularly with bogies of vehicles which carry the motors.

To prevent end batter, rail ends are sometimes hardened in America shortly after they are laid in the track. A short period after laying is considered necessary to enable the adjacent rail ends to be worked to a uniform level before hardening. Hardening is done by heating to a temperature of 1550° F for about 3 minutes with a gas jet and quenching for an equal period by compressed air.

211. Wear of rails—limits

In para 202, the relation between the axle load and weight of rails was shown. From this it would appear that the amount by which a rail may be allowed to wear would depend on the weight, reduced by wear, which would safely carry the prescribed load. If the prescribed permissible longitudinal stress in rails (15 tons per square inch) is not to be exceeded, the rail cannot be allowed

to wear more than approximately 10% of its weight. The approximate wear permissible in a 90-lb. rail cannot therefore exceed 9 lbs. As all the wear takes place in the head and as the head contains about 35% to 40% of the metal in the rail, the approximate percentage of permissible wear is about 25% of the section of the head. The prescribed limit of wear in India is 5% of weight if the maximum permissible axle loads corresponding with the rail section (*vide* para 202) are in use. It should be noted that if lighter axle loads than those for which the rail is designed are used, the percentage wear may be considerably increased without exceeding the stress of 15 tons per square inch. On curves, after the running edge of the outer rail is worn to the profile of the wheels, that is when the wheel flange fits the worn rail snugly, it becomes necessary to renew the rail even if the stress in the rail is less than 15 tons per square inch because of lighter axle loads. When wear to this extent has taken place, the flange of the wheel is likely to rub the fishplates or cut the fishbolts. The wheel flanges also have a tendency to mount the head of a worn rail when slight errors in the gauge or in the level of the track occur. The wear of wheel flanges has also to be watched. If the flange is worn until the contact face is vertical, the flange is likely to ride on the worn portion of the rail head and chip or break the head.

212. Renewal of rails

For purposes of making estimates, a rail is considered in India to give 60 years' service. This is naturally a very rough figure and the wear of rails in some localities may require their replacement or renewal within a considerably shorter period. Rails in electrified tracks, with the numerous trains which run over them, are subject to very severe wear. On one of the electrified suburban sections in India, with over 100 trains per day, 90-lb. medium manganese steel rails on a 3° curve with $n+5$ sleepers have been wearing at the rate of 0.3% per annum. On some American railways, rails are renewed every 18 months due to excessive wear on sharp curves (8° to 10°). Several other factors, apart from wear, have to be considered in deciding whether wholesale renewal of rails have to be carried out in a length of track. If rails are required for subsidiary or branch tracks, it is advisable to lay new rails in a main track and use the released rails in the branch track. If heavier locomotives are to be introducted, this may necessitate the renewal of existing rails in good condition with heavier rails. Again, rails may have to be renewed before they are worn the prescribed amount, if many rails are found either bent, or with elbows or kinks in them, or if their ends are bent vertically. A rail with a vertical bend is

variously termed as having *dropped ends* or as being *surface bent* or *hogged*. The worn condition of sleepers and fittings, requiring renewal may also be considered the right occasion for renewal of rails which have not been worn to the prescribed limit. Even if some lengths of rails are sufficiently strong and safe, but have other defects such as bends, etc. which makes travelling uncomfortable, renewal may become necessary.

Wear of rails in tunnels due to chemical action has been found in some countries to be four or five times that on open sections. Heavier rails with painted surfaces (except the running surface are used in such cases.

213. Reducing rail wear

There are several methods by which rail wear may be reduced. Special alloy steel rails are sometimes used in locations where wear is very great. A well maintained track, where joints have been given the attention they deserve, will not have as much wear on rail ends as a neglected track. Reduction in excessive expansion gaps reduces rail wear at ends; adequate tightening of fishbolts, and thorough packing of joint sleepers also help considerably in reducing wear. Battered ends of rails may be built up by the welding process and further deterioration thereby reduced. The battered ends are also sometimes cut off and the shortened rail re-used. A method of straightening hogged rails, without removing them from the track, has been successfully tried in India. Machining of the battered end of rail is resorted to on some railways with satisfactory results. Elimination of as many rail joints as possible, by welding together the rail ends, increases considerably the life of rails.

With rails on curves, the rail may be turned round, so that inner edges become the outer edges or the inner rails may be interchanged with the outer rails of the curve. The necessity for interchanging the inner rail with the outer rail, may be due either to heavy side wear of the outer rail or to heavy top wear of the inner rail. The advantage of this exchange consists in transferring the wear from the top to the side of the rail head and *vice versa* and the life of rails on curves is prolonged by this process. Yet another method of reducing wear of rails on curves is to introduce a check rail (Fig. 213) along the inner rail of the curve. The inner face of the wheel rubs against this check rail and the flange of the outer wheel is prevented from coming

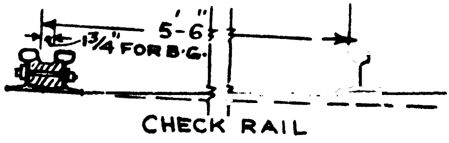


Fig. 213

in contact with and wearing out the side of the outer rail head. In India, check rails are usually provided with curves of 8° and over for B.G. and 14° and over for MG. As the check rails are invariably worn rails, unfit for through tracks, further wear of the check rails is not objectionable.

Turning of rails either on curves or on the straight in order to prolong their life is objected to by some track maintenance men on the following grounds. If the head is considerably worn, turning of the rail presents a smaller width of contact with the wheels and may reduce the hauling capacity of locomotives. The stresses in the rails are also altered and this is not considered desirable. The wheel load is thrown on the edge of the head and is not distributed on the web and similarly the weight is not distributed uniformly on the sleepers. It should be realised that some of the above objections hold good only if the head is considerably worn. It may also be stated that the common practice is to turn the rails when relaying them in another track.

Corrosion of rails due to adverse atmospheric conditions is being countered in America by flame cleaning followed by brushing and application of a rust preventer, all carried out by a unit with mobile equipment. In India, hand application of heavy mineral oil has been tried.

214. Rail lubricators

An important method of reducing wear on curves is by means of lubricators. The function of lubricators is to oil the side of the rail head where excessive wear occurs. There are many advantages of such lubrication. Wear of rails is considerably reduced, this reduction being found by experiment in some cases to be over 50%. The curve is maintained in better condition and the effort of keeping it in proper gauge and line is reduced. Speeds and loads of trains can be increased and the riding in vehicles over lubricated curves is more comfortable. Lubrication can be carried out manually or by mechanical devices, attached either to locomotives or to rails. The manual method is crude and is seldom used. Mechanical devices attached to rails are in favour. With such lubricators, oil is forced along the side of the rail head and is carried forward by passing wheels. The oil is forced through holes in a rail, or through holes in special bars touching the rail, or by means of lengths of special leather touching the side of the rail. The forcing of the correct quantity of oil is done in various ways. Plungers worked by the slight up and down movement of the rail under wheels, ramps on the outside of the rail depressed by wheels, vibration of a moving train, the capillary action of fluids, are some of the means employed.

215. Measuring wear on rails

The wear on rails is computed either by weighing the rails or by obtaining an accurate profile of the head of the rail. Either of these methods is suitable. The weighing of rails, although cumbersome, gives accurate results for the whole rail and is preferable when loss is also due to corrosion of the web and foot of the rails.

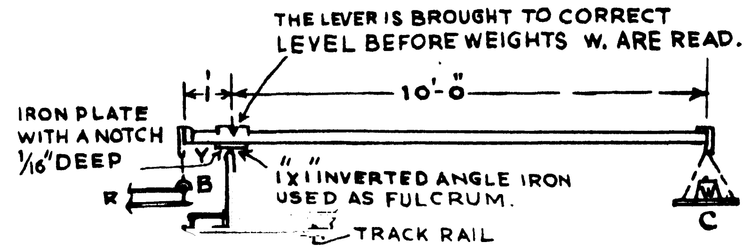


Fig. 215

On the other hand, measuring devices are handier and quicker and, as the wear is mostly in the head of the rail, the results are accurate.

The weighing of a rail is done by removing its fittings and suspending the rail from a light weighing machine. The rail is then refixed. The author has successfully used levers for weighment of rails. The device consists of a lever with its fulcrum so positioned as to divide the lever in the ratio of 1 to 10 (Fig. 215). One end of the lever has a clamp by which to grip the head of the rail and raise it. Small weights are placed in a pan at the other end of the lever. The levers work in pairs, one lever being used at each end of the rail. Their conveyance to the site is easy, as the weight of each lever is less than 20 lbs. The weight of the rail is 10 times the sum of the weight in the two pans plus a constant (238 lbs.). The constant is found from the equation (*see* Fig. 215)

$$(R+B)\,1+\tfrac{1}{2}Y=10\,(C+W)+5X$$

where X is the weight of the longer arm of the lever.

A simple measuring device consists of a large number of needles fixed in a frame which is in two pieces hinged together. The frame is fitted to the head of a rail and the needles pushed home. The frame is removed, with the help of the hinge and a profile of the rail head is produced by the needles.

A more elaborate measuring device consists of an instrument on the principle of the pantograph which enables the profile of

a rail head, picked out with a point on the instrument, to be recorded simultaneously on a piece of graph paper attached to a small vertical table on the instrument. The instrument is clamped to the rail of which a head profile is required. As each square on the graph paper represents a fixed weight, the loss in weight is obtained from the difference in the number of squares between the profiles of a full and the worn rail.

216. Corrugated or roaring rails

In certain places, heads of rails are found to be corrugated and when vehicles pass over such rails, a roaring sound is created which is intense enough to be unpleasant. The corrugations consist of minute depressions on the surface of the rail. They vary in shape and size and occur at irregular intervals. Corrugated rails are found under the following conditions, but the presence of any of these conditions does not necessarily result in corrugated rails.

(*a*) Where the ballast consists of broken bricks.

(*b*) Where brakes are applied to trains for stopping them.

(*c*) Where trains start.

(*d*) On electrified sections of a railway.

(*e*) In long tunnels.

Some of the peculiarities of corrugated rails are worth noting. If corrugation develops in any part of a rail, the whole rail gets corrugated in a short time.

Corrugations occur on any gradient, and equally on straight tracks and on curves.

When corrugated rails are re-laid in other sections, the corrugations sometimes get smoothened out; when new rails are laid in places where corrugation is prevalent, the new rails get corrugated.

No effective remedy has yet been found, for the simple reason that the cause has not been finally established. Several theories have been put forward, some of which are given here, but they have not been conclusively proved.

Some attribute corrugations to defects, such as excess phosphorus, in the composition of rail steel. Others contend that the resiliency of a track has a considerable bearing on this defect. Another theory, by which the presence of corrugations in all the localities mentioned above may be explained, is as follows.

If the metal of the wheel and the rail were infinitely hard and if the surfaces of the wheel tread and rail head were infinitely smooth, the wheel and rail would be in contact at a point or a line only. As such conditions do not exist, the wheel is in contact with the rail on a small area due to compression of the metal of both the wheel and the rail. The intensity of weight over this small area is not uniform, but is very great at its centre; it is possibly twice as great as the average intensity and probably exceeds the elastic limit (para 210). The metal at the centre of the point of contact becomes plastic, namely it is capable of being easily pulled. When a wheel slips over a rail due to one or more of several causes, it pulls away a minute particle of this plastic metal and this is the beginning of corrugation.

Yet another theory is that the wheel skids in time with the periodicity of the springing of the vehicle, due to bad joints or due to the application of brakes. Corrugations occur due to corrosion where the wheels do not touch the rails on account of the skidding. Such skidding would only occur under a particular combination of weight of track and nature of formation.

In Germany corrugations in rails are removed by grinding a few thousandths of a millimetre off the rail head.

Rail grinding trains on German railways move at 2 miles per hour when the grinders are in action.

217. Damaged rails

Rails may have to be removed from the track on account of their becoming unsafe, either due to normal wear, or due to defects developed through damage caused to them, or due to their failure on account of some defect in the manufacture of the rail. The various causes of wear have already been described. Damage to rails is caused by any one or more of the following reasons:

(*a*) Careless unloading or handling of rails.

(*b*) Bending rails to sharp curvatures.

(*c*) Unnecessarily striking the rail whilst fixing it to sleepers.

(*d*) Poor maintenance of track, including loose sleepers at joints, loose fishbolts, incorrect superelevation on curves, etc.

(*e*) Slipping or skidding of wheels due to overload or bad application of brakes. (It is desirable to differentiate between the terms slipping and skidding. Slipping of wheel occurs when the movement of the tread or tyre of

the wheel is greater than the forward movement of the axle or wheel. Skidding or sliding of wheel occurs when the forward movement of the axle is greater than the movement of the wheel tread.) Slipping of wheels burns the top of rail, whilst skidding produces flat spot on the wheel tread. Such flat spots affect the rail head adversely.

(*f*) Damaged tyres of wheels.

(*g*) Excessive speed due to which the defects, already existing in a rail, are increased.

(*h*) Bending or breaking due to an accident.

The damage in all cases may not be serious nor may it be sudden but these are the several contributory causes.

218. Rail failures

The sudden failure of a rail is generally due to defects in its manufacture, although other causes may also exist. Two such other causes, which are very common, are an abrupt change of section of rail or notches with corners in the foot of a rail. All notches should be rounded to prevent cracks from starting at the corners.

Failures due to defects in manufacture are very few in India. The position is different in America where over 5,000 failures (in a total track mileage of 235,000) due to a defect known as transverse fissures have occurred in a year.

Failures may occur in one or more of the following forms:

(*a*) *Crushed heads* (Fig. 218*a*) are rail heads which have flattened and sagged. Apart from defects in manufacture, crushed heads are due to slipping of wheels, flat spots on wheels, and weak support at the rail end. Weak end support may be due to loose fishbolts.

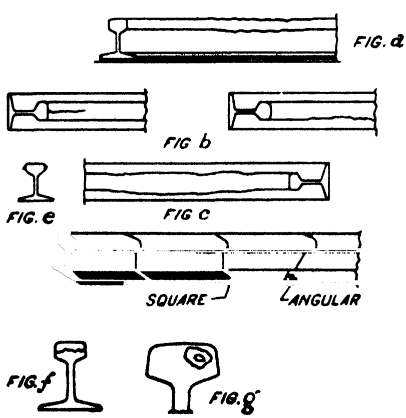


Fig. 218

(*b*) In *split heads* (Fig. 218*b*), cracks occur in the middle of the head or pieces are split from the side to end of the head. If the surfaces of the crack, when opened, appear smooth and dark, the defective rail is

known as a *piped rail* and this defect is due to a cavity formed (during manufacture) on shrinkage of metal due to the metal not having been closely welded together.

(*c*) *Flowing metal* in heads (Fig. 218*c*). The metal in the head is forced to the sides, the rail head being widened and depressed.

(*d*) *Square or angular break* (Fig. 218*d*). The rail may be completely broken either in a vertical plane or in an inclined plane.

(*e*) *Split web* (Fig. 218*e*). These generally, though not necessarily, run through bolt holes.

(*f*) *Horizontal fissures* in rail head (Fig. 218*f*). It is more in the nature of a fracture and develops gradually.

(*g*) *Transverse fissures* (Fig. 218*g*). This is the most common cause of rail failures in America. It is a crosswise break which starts from a point inside the head and spreads gradually. The broken surface has a smooth oval or round bright spot. The cause of transverse fissures is variously put down to defects in manufacture or to overstraining of metal in service. In view of the very heavy loads, high speeds and frequency of trains in America, as compared with India, coupled with the fact that such failures are very common in America, there appears to be some justification in the overstrain theory.

(*h*) *Horizontal cracks* at rail ends between head and web. Such cracks are believed to be due to worn fishplates, or insufficient ballast packing under joint sleepers, resulting in *pumping* of joints and consequent fatigue failure of steel. A method of field hardening of rail ends with a portable machine is being tried out in America to overcome this difficulty.

Horizontal fissures in the rail head or shelly rails are found to be increasing in U.S.A. This defect was formerly considered as due to fatigue caused by shearing stresses. Recent photo-elastic investigations appear to indicate the cause as the constant reversals of stresses in the rail between supports, from high compressive to low tensile stresses.

Rail failures reached such large proportions in America that a special detecting device known as Sperry Transverse Fissure Detector was introduced. In this device, a powerful current is passed through the rail. Any obstruction, such as a fissure, in its path interrupts the current and such interruptions are recorded automatically. At the same time, the interruption in current works a paint gun

which marks the defective rail. The detector, which is installed in a vehicle, moves over the tracks to be tested at a slow speed. The use of the detector car eliminates danger from sudden rail failures.

A simpler and hand-operated device called Sonirail Detector is used in India. It is an electronic device for testing rails and particularly for showing up web defects. It consists of a probe stick at the end of which is a detector crystal in an oil bath. The probe stick is attached to a Receiver-transmitter instrument which is powered by a battery. The receiver-transmitter carries a milliammeter as well as a loud speaker through which rail flaws can be detected as the crystal is slid along the top of the rail. The unit is very compact, weighs about 12 pounds including the probe stick; the receiver-transmitter and the battery are carried as two packs slung over the shoulders.

219. Welding of rails

Welding of rails is done either

(*a*) for building up (i) worn or battered heads at rail ends, (ii) portions burnt in the rail head due to slipping of wheels, and (iii) certain parts of worn points and crossings, or

(*b*) joining two or more rails to form longer rails, and thus overcoming the discomfort and weakness inherent in rail joints and reducing the cost of maintenance.

In the first case, the "life" of the rail is considerably extended, resulting in savings in expenditure, both in renewal and in maintenance. The vehicles have a smoother passage over the rails, and there is greater comfort for passengers and less wear and tear of vehicles.

The advantages of fewer joints in a track are so great that although welding together of rails into long lengths was started comparatively recently, considerable development has taken place in a short period. It is reckoned that from 20% to 40% of the maintenance of a track is taken up by rail joints. A rail joint with fishplates is not as strong as the rail and is a weakness in the track structure. A wheel, when it jumps the gap between rails, gives a blow to the receiving rail and the rail end gets battered. The fishplates also get worn, bent or broken. Due to such blows, the packing under the sleepers is loosened, which in turn results in the effects of further blows being intensified. Wear and tear is therefore considerably reduced both in rails and in vehicles by having fewer joints and the standard of comfort for passengers is thereby increased.

For welding together the ends of rails, four different methods of welding, known as Electric Arc welding, Oxy-acetylene welding, Chemical (*Thermit*) welding and Flash-butt welding are possible. Of these four methods, the most satisfactory is *Flash-butt* welding, but a heavy plant is required for this. Thermit welding does not require an elaborate plant. The electric arc and oxy-acetylene methods are excellent for building up worn rails, but are not generally used for joining rails together.

In the electric process, a current is passed through the rail as well as a thin rod, called an electrode. Electrodes for welding rails are made of metal similar to that of the rail and usually have a covering of special material. When the electrode, after having been brought in contact with the rail, is moved slightly away, an arc is formed possessing sufficient heat to melt the electrode as well as a portion of the rail near the electrode and molten metal from the electrode is deposited and mixed with the metal of the rail. In the oxy-acetylene process, the intense heat required for melting is produced by the oxy-acetylene flame, and molten metal from a rod is similarly deposited on the rail. The apparatus required for this process is very simple and portable. It consists of two containers, one for oxygen and the other for acetylene, together with a nozzle and various connections and gauges. Mobile electric welding sets are also available and consist of an internal combustion engine, an electric generator with its accessories and lengths of cables.

In chemical (*thermit*) welding, advantage is taken of a chemical process. When aluminium and iron oxide are mixed together in powdered form and ignited, intense heat (with a temperature of 3000° C.) is produced, which melts the components. The iron is separated and deposited between the ends of two rails which are heated beforehand. A chemical welding set consists of a mould lined with special sand, which can withstand high temperatures. The mould is fixed at the rail joint after removing the fishplates and bolts. A conical crucible is clamped to the rails and is held vertically above the mould. The rail joint is first heated with a blow lamp. Aluminium and iron oxide powder are then placed in the crucible, ignited, and the molten metal poured into the mould. The mould is then removed and the excess metal round the joint removed by chipping when still red hot. The joint is then annealed, namely heated to a high temperature and allowed to cool slowly.

In a variation of this method, a shim of special iron and of the shape of the rail head is inserted between the rail ends which are brought hard up against the shim with special clamps. The metal

is then poured from the crucible and the operations, explained above, carried out.

The method employed in *Flash-butt* welding, introduced in 1928, is to bring the ends of the rails together and pass a powerful electric current through them. The rails are then drawn slightly apart. This operation is repeated till the rail ends attain the requisite temperature. The rails are then allowed to remain in contact with each other and the flow of current is continued. This produces a flash, after which the current is stopped and the rails are pressed over together under a pressure of 20 tons. Flash-butt welding has been found to be very satisfactory, only 6 out of over 20,000 joints having been found defective on the London Underground Railways. Flash-butt welding plants were introduced in India in 1949.

In building up worn ends of rails, the electric or the oxy-acetylene methods are employed. In America, such work is part of routine maintenance. In India, building up of battered rail ends has not been carried out to any great extent but building up worn points and crossings is done on many railways. Details of this work will be found in para 2203. After the weld metal is deposited, the surface is ground carefully so that the correct profile of the rail is obtained. The success of electric and oxy-acetylene welding depends very much on the skill and care of the operator.

Out of the four welding processes, the first three can be carried out in the field without removing the rails from the track, whilst for flash-butt welding, the rails have to be taken to a welding plant which is much too large for moving about. After the rails have been welded by the flash-butt method, they have again to be transported for laying, and transport difficulties are increased as the rails are welded in long lengths. The difficulty has been overcome in America, where rails have been welded together by this method in lengths of over 1,400′ and transported on flat wagons. On the other hand, the cost of such welding is small compared to the other methods, provided a very large amount of welding is to be done, as the welding plant itself is costly. The plants required for electric, oxy-acetylene and chemical welding are not cumbersome but the cost of powders, electrodes, gases and liquid fuel have to be considered. Oxy-acetylene and electric arc welding plants have a further advantage in that any broken parts of a steel structure, apart from rails, can be repaired with these plants. The oxy-acetylene flame has a further advantage in that it can be used for cutting steel. Mobile flash-butt welding machines have been introduced in America. They weigh 18 tons and can be installed on a flat wagon. They can weld rails of sections upto 155 pounds per yard at the rate of 20 welds per hour. In India, arc

welding is generally employed for building up points and crossings whilst rails are being joined together by the flash-butt and chemical processes.

An interesting development in America, known as strip welding, is to repair battered heads at ends of rails by welding only a strip of metal along the centre of the table. The metal deposited is troostitic steel (para 2105) and due to its qualities is said to last as long as a fully welded head and to be more economical.

220. Long welded rails

As the weakest part of the track is the rail joint, the elimination of as many rail joints as possible by welding is desirable. The lengths to which rails have been welded in India since 1939 are 210′ (5×42′) and 216′ (6×36′). Such welded rails have proved very satisfactory. On large bridges the practice is to use one length of rail on each span and introduce special expansion joints at the ends of each span.

Experience in other countries indicates that welded rails upto a length of 300 ft. require no special provisions for expansion. On some railways in other countries lengths of 1,000 metres, 1,500 metres and more are used. In France welded rails of 800 metres have been standardised with switch blade and stock rail type of joints at each end.

Welded rails are allowed on curves with a minimum radius of 800 metres in France and 600 metres in U.S.S.R, Poland, Switzerland and Spain. On M.G. track, welded rails have been laid on curves with 200 metres radius.

The method of fixing welded rails to sleepers is important. The rails must be either held down tightly or must be fixed by a spring device which creates a permanent pressure between the rail and the sleeper.

The section of ballast in the track is an important consideration with welded rails in order to preserve track alignment against temperature strains in long rails.

The feature of a welded rail to be guarded against is the tendency of a long rail to buckle due to temperature variation, since expansion and contraction are partly restrained. Observations indicate that the actual expansion and contraction of a long welded rail is much less than the theoretical value, and the total movement at the ends of long welded rails is not greater than that of the normal rail length. This is due to the restraint on the rail through

friction between the rail and its seat on the sleeper and also through creep anchors.

If a rail is totally restrained against expansion or contraction, a stress of 195 p.s.i. (pounds per square inch) is induced in the rail for every one degree variation. Assuming the maximum range of temperature in India as 130° F., the stress induced in the rail is $195 \times 130 = 25{,}350$ p.s.i. or 11.3 t.s.i. If the rail is laid at the mean temperature of 65°, the corresponding rail stress is 5.6 t.s.i. The difference between shade and rail temperature may be taken as 30°. With welded rails of 216′ the maximum shade temperature recommended for laying is 90° F.

A long welded rail under a stress of 11.3 t.s.i. would buckle, but is constrained from deflecting laterally by the rail fastenings, sleepers and ballast. A theoretical analysis based on a comparison with a long column on an elastic bed, the reactions from which are taken proportional to the deflections at points along the column, shows that the minimum temperature stress in the rail which will result in buckling (critical load in the column analogy) is almost alike for a welded rail of 216′ length and an infinitely long welded rail.

The same view is held in America where 100-lb. to 131-lb. rails welded to a length of 6,982 feet have been in existence since 1930, in an area with a maximum temperature variation from—30° F. to 120° F., the track carrying over 50 trains per day with a maximum speed of 60 m.p.h.

With regard to the possibilities of buckling with long rails, it is considered that the actual stresses are less than the theoretical stresses and that seasonal temperature fluctuations give rise to what has been described as adaptation phenomena by which some kind of flow takes place in the metal which tends to return to the neutral state without changing its dimensions.

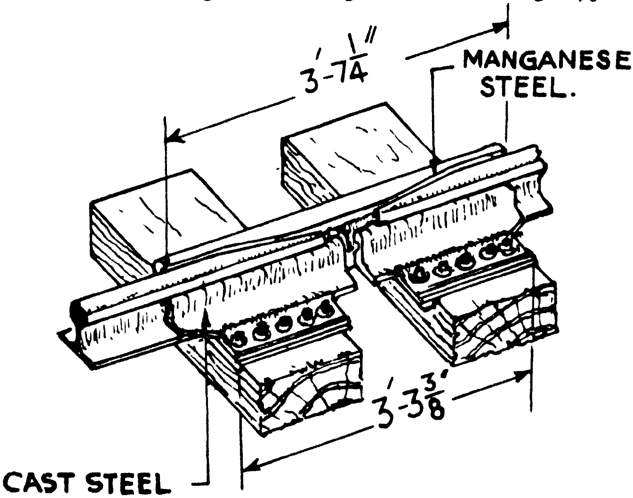
It must however be remembered that the sleeper density in America is greater than in India. The capacity of a track to resist buckling is the chief consideration in a welded rail track and this capacity is governed by the ballast section, sleeper density and weight of track. Full restraint is not possible and depends on the length of the welded rail. If the length is limited to 100′, the expansion is reduced by 60%, i.e. the restraint required is 40%. This restraint increases with increase in length of welded rail. Restraint with wedge (loose jaw and key) type, clip bolt type or elastic fittings is far greater than with dog spikes. An increase in sleeper density also increases the restraint.

In long welded rails, it has been found that expansion of rails takes place at the two ends over a length of about 240′ to 300′. As large gaps cannot be left at the joints to accommodate this expansion, a switch type of joint, which permits large movements of rails, is introduced. Another type of expansion joint used with long welded rails is shown in Fig. 220. Alternatively, and sometimes in addition, creep anchors are provided over these end stretches.

In the rare cases of damage to a rail, through any cause whatever, the damaged portion has to be cut out and another piece welded in its place.

Anchoring of welded rails, particularly at ends of long welded rails, is important. For very long lengths anchors have been applied at every sleeper for 240 ft. at each end of the rail.

Considerable savings in maintenance are effected through welded rail track, the figure of savings in France being 24% and in



DETAILS OF EXPANSION JOINTS

Fig. 220

Germany 17%. The advantages of a long welded rail track with heavy concrete sleepers are extensive enough for this practice to be considered the greatest recent contribution to railway track.

221. Heat treatment of rails

The physical properties such as strength, hardness, toughness, brittleness, etc. of metal depend to a certain extent on heat treatment

(*vide* para 1805). Heat treatment of rails is being increasingly adopted in America. In addition to controlled cooling applied as a protection against the development of transverse fissures, rail end hardening is extensively practised to reduce batter of the rail at the joints. Rails are also heat treated, throughout their length, particularly for use on sharp curves, so that the periods between rail renewals may be increased. Welded rail joints are also heat treated to make them tough and thus give the rails a longer life.

222. Brands on rails

Every rail has a brand on its web and, in case of rail failures, the data given on the rail have invariably to be included in the failure report. The various letters and figures show details of manufacture.

The markings are preceded by an arrow and also end with arrows. In the old rails the first letters give the initials of the railway, e.g. B.B. & C.I., B.N., G.I.P. etc. The weight of rail and type of section are given next, e.g. 90 R.B.S., which means that the rail weighs 90 lbs. per yard and is of the Revised British Standard section. The initials of the manufacturers come next, e.g. T.I.S.Co., to represent Tata Iron and Steel Co. The month and year of manufacture are then marked, the cast number is distinctly stamped at both ends. In case of special alloy rails, such as manganese steel and chrome steel rails, the letters M.M. and Cr. are marked on the web at intervals of 5′ to 6′. On certain rails a star is found on the side of the head near the end of the rail, on others a $3\frac{3}{8}''$ dia. ring is marked in a similar place. On the section of the rail adjoining the starred end a number is also to be found.

The significance of the arrows, stars, etc. is briefly as follows. The steel from which rails are rolled is initially in the shape known as an *ingot*. The ingot is made thinner by rolling whilst very hot and the result is called a *bloom*. The blooms are cut into pieces and rolled into rails. The arrows indicate the direction of the top of the ingot. The star indicates the end of the topmost rail rolled from the top portion of the ingot and the ring indicates the bottom end from the lowest part of the ingot. The figure on the section of the rail near the star shows the cast number. All this information is necessary for inspection and testing purposes. Rails which do not conform with rigid specifications, in that they have slight surface defects or some tolerance in chemical composition, may be used on loops and sidings where speeds are restricted to 20 m.p.h. Such rails, in addition to the above marking, have the letters QL-2 stamped on their webs at 10′ intervals.

Sleepers

301. General

RAILS in a railway track need support and the greater the support, the lower are the stresses induced in the rails. The two parallel rails forming a track have also to be kept an exact distance apart and this is done with the help of sleepers. The chief functions of sleepers are to support rails, distribute the load from the rails to the ballast and keep the two rails of a track to correct gauge. The position or alignment, surface, level and gauge of railway track is constantly disturbed by the passage of vehicles and the track has to be constantly adjusted. A sleeper has to be of such design as to counteract such tendencies. It was considered an advantage to have fittings on sleepers which would permit widening of gauge on curves but as the gauge is not widened now for curves under 4½° and as the number of sharp curves is very limited, fittings permitting gauge adjustments are not being provided now. The fittings should also be such as to allow either a rail or a sleeper to be easily removed or introduced. The sleeper should have a sufficient rail bearing area to prevent the rail from crushing the

sleeper at the rail seat, or cutting the rail seat along either edge of the rail foot. In the latter case the rail would be tilted.

302. Various types of sleepers

Sleepers originally consisted of slabs of stones or longitudinal baulks of timber laid under the rails. Both these types were discarded, as in the first case the running was rough and the noise was very great. Longitudinal sleepers were found to be expensive as they had to be of a large section to satisfactorily support the rail and the cost of timber increases rapidly with increase in section. Additional timber was also required to hold the two longitudinal timbers to correct gauge.

Cross sleepers, which were first introduced in 1835, are now employed universally. They are made of wood, steel, cast iron or concrete. A sleeper that fulfils all requirements most satisfactorily is the wooden sleeper. As the number of sleepers required is enormous and as timber is becoming scarce, sleepers of other materials are being used in increasing numbers in many countries, particularly in India. One of the shortcomings of metal or concrete sleepers is that if any wheels are derailed the damage to these sleepers is substantial as compared with wooden sleepers. Again, in track circuiting (*vide* para 2310) rails are used as conductors of a very small current. The rails laid on wooden sleepers are automatically insulated, whilst special insulation is required between rails and other sleepers. On the other hand, metal and concrete sleepers have better fittings for holding the rails and the wear is less than on wooden sleepers. A track on metal or concrete sleepers is also less inclined to be thrown out of position than one on wooden sleepers as the shape of metal sleepers and the weight of the concrete sleepers increases the strength of the track in the lateral direction. Metal sleepers have been used on a large scale in countries where deterioration of wooden sleepers due to the presence of vermin, e.g. white ants, and on account of climatic conditions is rapid. In Britain, treated wooden sleepers last about 20 years in the main tracks and then give further service in sidings, whereas the life of a wooden sleeper in India is considered to be 15 years. On the other hand, in most climates, steel corrodes rapidly and it has been found in Britain, that although the life of a steel sleeper based on wear only, is nearly 50 years, corrosion and localised wear tend to render them unfit in a much shorter period. Cast iron sleepers, although used extensively in India and South America, are little used elsewhere. In India, they are giving good service. Concrete sleepers both of the reinforced block type and the

prestressed concrete type are being used increasingly in Europe. In determining the relative advantages of sleepers of various materials, consideration has also to be given to their value as scrap when they are discarded. Cast iron has the highest scrap value followed by steel. Wood and concrete have little value as scrap.

Steel sleepers are usually in the form of shallow inverted troughs with special fittings to hold the rails (Figs. 309*a* and 309*b*). In drier climates, steel sleepers last much longer than in wet areas and are therefore in great demand in countries like India. Corrosion might at some future date be reduced by the use of alloy steel containing copper.

Cast iron sleepers were formerly in the form of circular or oval bowls or pots (Fig. 310*a*) and also in the form of flat plates with projecting ribs at the bottom (Fig. 310*b*). The present cast iron sleepers are a combination of pots and plates. Pots and plates are used in pairs with a connecting piece formerly of wrought iron and now of steel. These connecting pieces are known as *tie bars* and hold the rails to correct gauge.

Concrete sleepers have all the advantages of a material which is immune to corrosion, and vermin attack. Two types have become popular, i.e. the reinforced concrete block type with a tie bar and the prestressed concrete through type.

In recent years, in order to save material, separate blocks of wood and sometimes of reinforced concrete have been used under each rail with no connection between each pair of blocks to hold the gauge. Every alternate sleeper or every third sleeper is an ordinary through sleeper. Such combination may be used safely on sidings and unimportant lines and their advantage lies in economy.

Track circuiting (*vide* para 2310) which is being increasingly used in signalling practice, requires that the rails should remain electrically insulated from the sleepers. Hitherto wooden sleepers, which have good insulation value, have been used, but other types of sleepers such as concrete can also be used provided insulating pads of rubber (particularly the more durable synthetic rubber such as Neoprene) are introduced between the rail and the sleeper. Such synthetic rubber pads have also been tried with steel sleepers.

303. Size of sleepers

The depth of a sleeper governs its stiffness and the length and width govern the permissible bearing on the ballast. In the case of wooden sleepers, the strength of the different types of timbers

also affect the size. For instance, a sal sleeper is 50% stronger than a deodar sleeper and a sal sleeper of width 10″ and depth 5″, namely of a section 10″ × 5″ is stronger than a deodar sleeper of section 9″ × 6″ and is equally stiff, although the depth is 1″ less and even though stiffness varies as the cube of the depth. A sleeper is not packed with ballast throughout its length, but hard packing is done under the rail seats only. The length packed is from the rail to the end of the sleeper and an equal distance in the inter-rail space. The reason is that each rail must be supported uniformly on either side. It has been reckoned in America that the cheapest way of increasing the supporting power of a track is by increasing the length of sleepers. In computing the bearing area, 4″ are deducted from the length of the sleeper at each end as it is considered that the end 4″ of the sleeper is not effective in bearing the load. In India, a 9′ long sleeper is assumed to have 1′-6″ bearing length on either side of each rail. This gives a bearing area of 5 sq. ft. per sleeper. The end 3″ of the sleeper are not considered effective. The bearing area of a metre gauge sleeper is 3.33 sq. ft., the effective bearing length on either side of each rail being 1′-3″; the bearing area of a narrow (2′-6″) gauge sleeper is 2.26 sq. ft. The length of a sleeper on a smaller gauge cannot be reduced by the difference in the larger and the smaller gauges, as with smaller gauges the vehicles have a greater tendency to lurch and this throws a load on each end of a sleeper greater than half the axle load.

The standard size of wooden sleepers, in India, is 9′ long × 10″ wide × 5″ deep for broad gauge, 6′ × 8″ × 4½″ for metre gauge and 5′ × 7″ × 4½″ for narrow gauge. In America, with 4′ - 8½″ gauge and heavier axle loads, the standard size is 8′-6″ × 9″ × 7″, and the tendency is to further increase the length to 9′. About 40 years ago, the size was 8′ × 8″ × 6″. The length of steel trough sleepers, in India, is 8′-9″ and the troughs are generally 6″ wide on top, 10″ wide at the bottom and 4″ deep. Sleepers, longer than the standard size and of varying length, are required for switches and crossings and the lengths are increased by 1 foot upto 16′. The longer wooden sleepers are made of 12″ × 6″ section.

Mention was made in the previous paragraph of blocks of wood. The length of such blocks used is 2′-9″ and not more than two pairs of blocks are used between a pair of through sleepers.

In India, a standard wooden sleeper has a proper rectangular section throughout its length. In America circular sides are permitted provided the timber in the circular sides is in addition to that required for the specified section. Half-round sleepers are sometimes used for branch lines or light railways in India and elsewhere. These consist of logs split into two. The flat surface is laid on the

ballast and the uneven round surface on top is planed under the rail seat only.

On girder bridges with open decks, sleepers thicker than the standard sleepers are used and the length of such sleepers is specified as 12″ longer than the distance from the outside edge of one girder to the outside edge of the other parallel girder (girders are invariably used in pairs). The thickness of sleepers has to be varied to make allowances for the thickness of cover plates which are used for connecting, either with rivets or by welding, lengths of plates forming the flange of a girder. As girders are cambered or bent a little upward, presenting a slightly convex surface on top, an allowance was formerly made for this also in the thickness of the sleepers. The present practice is not to make any allowance for camber, unless the camber is greater than the amount by which the girder deflects when a train goes over it. The sleepers are spaced sufficiently close to prevent the wheels of a derailed vehicle falling through the space between adjacent sleepers. This maximum space allowed on B.G. is 20″, on M.G. 12″ and on N.G. 10″ between edges of sleepers. As rivet heads of girders project above the surface of the girders, notches are cut in the base of the sleepers to clear these rivet heads. It is easier to cut grooves to avoid rivet heads, as rivets are usually in straight rows. In America, sometimes notches or grooves are not cut in soft wood sleepers and the weight of the first few trains is expected to press the sleepers down on the rivet heads. This practice cannot be recommended with hard-wood sleepers and is obviously not possible for random renewal of sleepers. When new sleepers have to be trimmed to obtain the exact depth, such trimmings should be done on the lower face of the sleeper as trimming the top face leaves pockets for moisture and is also not very pleasing in appearance.

304. Sleeper density

The spacing of sleepers in a track depends on the axle load which the track is expected to carry and the lateral thrust of locomotives to which it is to be subjected. The number of sleepers in a track is indicated by the number per rail length.

If the rail is n yards long, the number of sleepers is n, if there is one sleeper per yard of rail. If the sleepers are spaced closer than one yard, the number is given as $n+1$, $n+2$, etc. For instance, if there are 17 sleepers in a 42′-rail length, the number of sleepers are $n+3$ since the number of yards in 42′ is 14.

The stiffness of a track is increased either by increasing the weight of rails or by increasing the number of sleepers and the

adoption of one or other of the methods depends on the comparative cost of rails and sleepers.

The number of sleepers cannot however be increased indefinitely as a certain minimum space between sleepers is required for packing of ballast. In India, where packing is done with flat-headed picks or beaters, this minimum distance is considered to be about 12″ to 14″ except at joints. In America, where tie tampers are used, 10″ are considered sufficient.

The number of sleepers per rail length varies in India from $n+3$ to $n+6$ for main tracks. In Britain, $n+4$ sleepers are used, whilst in America, $n+9$ to $n+11$ sleepers are common in through tracks. This very large number of sleepers in America compared to other countries is due to the very heavy axle loads used there.

If joints on a curve are staggered, an extra sleeper is required per rail length as each joint requires a sleeper on either side of it.

All sleepers are not spaced an equal distance apart. Sleepers on either side of the joints are kept close together, the spacing sometimes being reduced to as little as 2″; on occasions the joint sleepers are made to touch each other. Two or three sleepers adjoining the joint sleepers are also spaced closer than the remaining sleepers.

The $n+x$ formula for sleeper density does not indicate maximum sleeper spacing with different lengths of rails. Maximum sleeper spacing is an essential consideration. The author suggests a formula n_y+x which will indicate the same maximum sleeper spacing for any length of rail. In the formula, n is the length of rail in yards, y indicates predetermined joint and shoulder spacings and x is the density. The factor y indicates predetermined values, say 1′-6″ and 2′-6″ of joint and shoulder spacing respectively. Any variation with joint and shoulder spacing is possible.

An example will illustrate the position. Suppose

a means 1′-6″ joint spacing, and 2′-6″ shoulder spacing, and
b means 1′-0″ joint spacing, and 2′-3″ shoulder spacing.

Then with a 42′ rail

n_a+3 sleepers will indicate
14+3, i.e. 17 sleepers with 1′-6″ joint spacing, 2′-6″ shoulder spacing, and 2′-6 $\frac{7}{16}$″ inter-spacing.

whilst n_b+3 sleepers will indicate

14+3, i.e. 17 sleepers with 1′-0″ joint spacing, 2′-3″ shoulder spacing and 2′-7$\frac{1}{4}$″ inter-spacing.

305. Wooden sleepers

Timber obtained from deciduous, i.e. broad-leaved trees is relatively hard, e.g. teak and sal, whilst that obtained from coniferous trees, namely with needle-shaped leaves, is usually soft, e.g. pine and chir. The life of a wooden sleeper depends on its ability to resist (*a*) wear, (*b*) decay and (*c*) attack by vermin. Soft wood becomes unserviceable earlier than hard wood, as the flat-footed rail cuts into the soft wood easily. This defect is reduced by using a steel or cast iron bearing plate between the rail and the sleepers.

Timbers most commonly used for sleepers in India are sal, teak (these are hard wood), chir and deodar (these are soft wood). Sal is both heavier and stronger than teak, whilst the weight of chir and deodar is about two-thirds that of teak and their strength about two-thirds to three-fourths that of teak. Sleepers are also made from other indigenous timbers.

Sal grows profusely all over India and by far the greatest number of wooden sleepers in India are of this wood. It lasts long and does not require bearing plates for moderate axle loads.

Chir and deodar are soft wood and are obtained in large quantities in the foothills of the Himalayas. Unless treated, they do not last long.

The most commonly used timber in Britain for sleepers is Baltic redwood or fir. They are used after treatment and last as much as 20 years.

In America, the timber formerly used most extensively for sleepers was oak, but due to its increasing scarcity, other timbers mostly soft wood, such as pine and fir, are now used. The demand for wooden sleepers is enormous in America as the track mileage is about six times that of India and metal sleepers have not been used to the same extent as in India.

The section of a wooden sleeper is an important item. A square section is obtained from a circular log with the least amount of wastage, hence it is the most economical. The standard Indian section for B.G. which is $10'' \times 5''$ is a square section divided into two.

306. Timber defects

Timber contains several defects which are detrimental to their use and sleepers therefore need careful inspection. This inspection

is considered so important that there is a special organisation for inspection in India. Most of the wooden sleepers are supplied to Indian railways through this organisation. The defects which have to be avoided in sleepers are *sapwood, cracks, wanes, shakes, split ends, bore holes, knots, warps* and *unseasoned* timber. *Sapwood,* which is the outer soft portion of a tree, decays rapidly; it is easily detected due to its lighter colour. When sections are cut from a log which is not of sufficient diameter, sleepers are obtained with edges which are not rectangular and which also contain sapwood. Lack of wood at corners is known as *wanes.* Ends of sleepers have a tendency to split when seasoned or when excessive loads are put on them. *Split ends* are avoided by either clamping, or bolting, or tying the ends with wires, or driving pieces of hoop iron bent to various shapes, e.g. S shape, into the ends of sleepers. Clamps are made of flat iron, in two pieces, and bolted together. Bolts with circular or square washers, about 4″×4″, are common. Wire binding of sleeper ends is done either by twisting a loop of wire round the ends, with or without heating, or by first compressing the sleeper end in a clamp and releasing the clamp after the wire has been tied.

Wooden sleepers are invariably laid with the *heart* side on the ballast. The centre of a log shows concentric rings, each of which represents a year's growth. The centre of these rings is known as the heart. If the sleeper is laid with the heart side on top, the annular rings tend to open, moisture gathers in these rings and the sleeper decays. A sleeper *warps* when any of its surfaces bends from the true surface or plane and such sleepers are liable to alter the gauge and camber of rails. A *twisted* sleeper is one in which the surfaces are not in one plane, due to the sleeper being twisted whilst drying out.

Bore holes are holes of various sizes made by insects. As moisture enters these holes, the timber is liable to early decay.

Knots are more or less circular or oval pieces of hard wood and occur where branches take off the trunk of a tree. They are harder than the surrounding timber.

A living tree contains juices known as *sap,* and after the tree is cut, the sap has to be dried before using the timber. This is known as *seasoning.* Unless the sap is removed, the sleeper tends to bend, twist, warp and decay. Seasoning is done by exposing the cut timber to air. The timber should be stacked in such a way that air circulates all round it. It takes from 6 to 12 months to season timber. Seasoning can also be done artificially by steaming and drying the timber in a kiln.

307. Treatment of wooden sleepers

The life of a sleeper is prolonged considerably by treatment, as decay and vermin are largely eliminated. An extra life, varying from 30% to 50%, has been estimated for treated sleepers over untreated sleepers.

In the fibres of timber there are millions of minute cells. The cells contain juices and when these juices ferment, the fibres decay. Treatment consists in removing as much as possible of the juices and filling up the cells with a preserving solution. The solution used is either an oil or a salt solution and several varieties are used. All timbers do not require treatment to the same extent. For instance, sal is not usually treated.

Creosote is an oil which is generally favoured. It is composed of coal gas and coke oven tar. Some of the salt solutions used are chloride of zinc (Burnetising process), and Bichloride of mercury (Kyanizing process). Sometimes creosote and salts, such as zinc chloride, are mixed together for treating sleepers. There are three methods of impregnating timber. In the *full cell process*, the cells are completely emptied and an oil is forced under pressure so that the cells are completely filled with the oil. In the *empty cell process*, air is forced into the timber cells followed by oil, also under pressure. When the pressure is released, some oil is forced out by the air trapped in the cells. In the empty cell method, less oil is used and the sleeper does not ooze oil, as is the case when the full cell method is employed. In the third method, no pressure is employed but a salt solution is allowed to soak into the sleeper over a long period. There is yet another method (Haskenising process) in which the sleepers are subjected to high temperatures and pressures. The natural juices are said to be rendered harmless by this method. Creosoting is the treatment most commonly employed. In this process, the sleepers are placed in a cylinder about 90′ long and about 6′ diameter, in which they are heated to about 175° F. A vacuum is then created in the cylinder. This extracts all the juices. Without destroying the vacuum, creosote is pumped into the cylinder at a pressure of 75 lbs. to 150 lbs. per square inch. The cylinder is then drained of oil and the treatment is complete. The amount of oil forced into each sleeper varies, but about 10 to 15 lbs. per cubic foot of timber are sufficient. Impregnation with salt solution is cheaper as it does not require expensive plants, but the salt solutions are liable to be washed away from the sleepers by rain and as they are poisonous they are also a source of danger to those handling such sleepers. Treatment of sleepers is carried out extensively in America and in Britain where soft wood is mostly used, but only to a limited extent in India. Any cutting, boring

of holes, etc. is done before treatment. In case further cutting is done after treatment, the cut surfaces are liberally smeared with creosote oil.

Sometimes untreated sleepers are painted. This has some effect on preservation of timber in that it prevents moisture from entering the wood as long as the paint is intact. The ends of sleepers should not however be painted as it leads to decay known as *dry rot.*

308. Care of wooden sleepers

The durability or the lasting quality of a wooden sleeper depends on the type of wood, seasoning, treatment, if any, climate, axle loads and speeds of trains, location of the sleeper, namely, whether on a curve or a straight length, presence or absence of bearing plates and the care which has been taken of it in service.

If the ends of sleepers are bolted, clamped or tied with wire, as already mentioned, splitting is prevented. The spikes with which a rail is held to the sleepers should not be driven in one line on the sleepers but should be staggered to prevent splitting. The rail gradually cuts into the sleeper, particularly where heavy axle loads are used, and the sleeper may eventually become unserviceable through such wear. Bearing plates, if used between the rails and sleepers, distribute the load from the rail to the sleeper and prevent crushing of the sleeper. Bearing plates are known to extend the life of sleepers by as much as 30%. Even with bearing plates, the timber under the bearing plate gets gradually destroyed. It gets fibrous if the sleeper is of soft wood or soft and rough, if of hardwood. Such conditions pertain mostly in America with its heavy axle loads. Due to the constant side thrust of wheel flanges on rails, the spikes get pushed out and the gauge is widened, particularly on curves. Also due to wave motion of rails, the spikes are drawn up slightly from their holes and alternate re-driving and drawing up loosens them. Re-spiking has therefore to be carried out occasionally. When doing this, the old spike hole should be plugged and a new hole bored for the spike. Special compounds which become plastic on heating, are sometimes used for filling spike holes. Spikes driven in holes filled with such compound are expected to withstand a pull of 4,000 lbs.

The stacking of sleepers before use, has an important bearing on its life. The sleepers should be stacked on a well drained plot of ground which should be cleared of all vegetation for at least one foot all round the stack. The sleepers should be raised slightly above ground and should be stacked in such a way that

there is free circulation of air. The best way of stacking sleepers is shown in Fig. 308. The top of the stacks should be covered with a thin layer of earth to prevent direct rays of the sun on the sleepers and to mitigate the danger of fire from sparks of locomotives. Treated sleepers should be stacked solid so that air does not circulate round the sleepers, as treated sleepers are liable to crack with quick drying.

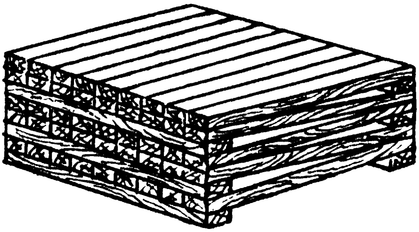


Fig. 308

When wooden sleepers are worn or decayed and require to be renewed, the question arises as to whether wholesale replacement, namely through renewal, should be carried out or only the bad sleepers should be renewed (random renewal). With through renewals, an excellent track is obtained after the new sleepers have settled down. From the sleepers released, the serviceable ones can be used on less important lines and sidings. With random renewal, the renewed sleeper does not settle down for some time and if there are many sleepers renewed in this way, the running of the track deteriorates. The cost of random renewal is also higher than that of through renewal. On the other hand, maximum life is obtained by the method of random renewal. Perhaps the best policy is to carry out through renewals on a main line and use the serviceable released sleepers for random renewal on branch lines or sidings.

A machine known as a *Tie-master* is used in America for removing an old sleeper from the track, preparing the ballast bed and placing a new sleeper. The operation takes one minute with three men.

When carrying out random renewal, the ballast is removed all round the sleeper to be taken out, the spikes are pulled out and the sleeper drawn out from under the rails. The new sleeper is inserted and the operation repeated in the reverse sequence. In America, the practice is to cut the sleeper with portable power saws on the inner side of the rails, remove the three pieces into which the sleeper is cut and insert a new sleeper in the gap. For through renewals, the rails are removed and after the sleepers have been renewed, the rails are refixed.

When wooden sleepers are laid in the track, it is usual to mark the last two figures of the year in which it is laid on the sleeper.

The type of wood used is also marked by a letter. For instance, S. 54 indicates a sal sleeper laid in 1954, whilst T. 60 means a teak sleeper laid in 1960. The figures and letters are usually cut on the top surface.

In order to obtain the cant of 1 in 20 for the rails, wooden sleepers are adzed to form a table at this slope at the rail seat. Accurate adzing is essential, otherwise the track will ride rough due to the cant varying from sleeper to sleeper. The sleeper is also liable to wear and decay as the rail does not rest fully on a roughly adzed surface and moisture collects between the rail and the sleeper. Where canted bearing plates are used, sleepers do not have to be adzed.

Care is to be exercised in driving spikes for holding the rail to the sleeper. The spike must be held and driven vertically, otherwise the gauge will be affected. Spikes are driven into bored holes. The boring of holes should also be done accurately, otherwise the spike will not be fixed in the correct position.

309. Steel sleepers

India uses metal sleepers more than any other country, and thousands of miles of track have been laid in India on both steel and cast iron sleepers with excellent results.

Steel sleepers have to be designed so as to fulfil the following conditions:

(*a*) The sleepers should maintain perfect gauge.

(*b*) It should be possible to fix the rails easily in the sleeper and without moving the sleeper longitudinally.

(*c*) The rail should have a sufficient bearing area on the sleeper.

(*d*) The sleepers should not be capable of being pushed easily out of position.

(*e*) They should have an effective bearing area on ballast at least equal to that of wooden sleepers.

(*f*) They should be made of metal sufficiently thick and of a shape such as to make the sleepers strong enough as beams.

(*g*) They should be so designed that packing or tamping does not damage the edges.

(*h*) They should be sufficiently heavy for stability.

(*i*) Where track circuiting exists, it should be possible to insulate them from the rails.

Steel sleepers in use in India fulfil all the above conditions except the last and the practice, at present, is to use wooden sleepers in track-circuited lengths. Insulation with synthetic rubber sole-plates is now possible.

Steel sleepers possess several advantages over wooden sleepers, although there are several points to offset these advantages. Steel sleepers are free from decay and attack by vermin, but on the other hand they are liable to corrosion. It is good practice to avoid steel sleepers in station yards where corrosion is heavy due to moisture and acids from refuse. They should also not be laid in any type of ballast except stone, and they should not be used close to the sea or in very wet or marshy areas. Cast iron sleepers have been laid where the track is within 10 miles of the sea and steel sleepers have been used on the remaining lengths. Steel sleepers are usually dipped in hot tar after manufacture as a protection against rust, but such protection cannot be renewed on the under side of sleepers.

The life of a steel sleeper is very much greater than that of a wooden sleeper, particularly in India. A steel sleeper lasts about 35 years compared to about 15 years' life for a wooden sleeper. The cost of a steel sleeper however is proportionately higher.

Track laid on steel sleepers does not require as much attention as that on wooden sleepers, particularly as renewals are not fre-

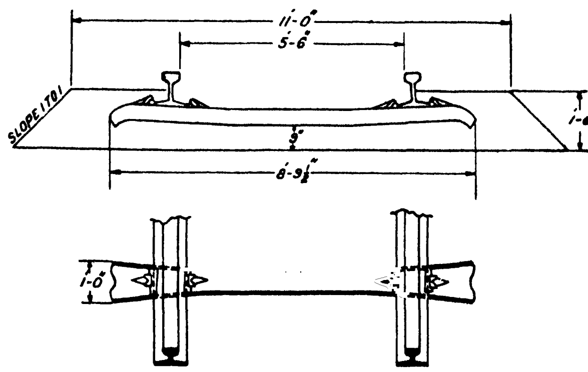


Fig. 309*a*

quent. The connection between the rail and the sleeper is much stronger than that with wooden sleeper. Also, steel sleeper tracks have far greater lateral rigidity than wooden sleeper tracks. When wedges are used for holding the rail between raised *lugs*, steel sleepers are found to crack at the corners of the hole which is left by the pressing up of lugs (Fig. 309*a*). This is due to the metal

being weakened by the holes near the rail seat which is the portion that is strained most in the sleeper. This defect is overcome when sleepers with clips and bolts (Fig. 309*b*) or separate jaws are employed for holding the rail. The pressed lugs are also liable to tear due to the side thrusts of vehicles and over driving of wedges or *keys*. The lugs are therefore strengthened by a small length of metal being pressed up behind and at right angles to the lug. Also light hammers are used for driving the keys. Steel sleepers for B.H. rails have chairs or brackets riveted, bolted or welded to the trough. Steel sleepers specially designed for points and crossings are being used with success.

There are two distinct types of steel sleepers, one in which wedges or keys are used for holding the rails in pressed up lugs or in *loose jaws* fitted in holes in the sleeper (Fig. 309*a*) and the other in which clips and bolts are employed for the same purpose (Fig. 309*b*). The sleeper consists of a trough or channel made out of steel about $\frac{1}{4}''$ thick and with its ends bent down to prevent ballast from running out. Lugs are cut and pressed to correct shape at the rail seats and the rails are fixed in these lugs either with a wedge or key, one on either side of the foot of the rail or with one *distance piece* and one key per rail. The distance piece is necessary as without it the two lugs would have to be closer than the width of the foot of the rail (unless the key was made very thick) and insertion of the rail would be difficult. The grip on the foot of the rail would also not be satisfactory. Sleepers with distance pieces and keys known as *two-key sleepers*, were in general use previously, but those with four keys are favoured now. The reason is that the gauge can be adjusted accurately with a *four-key sleeper*, whereas with a two-key sleeper if the outer lug

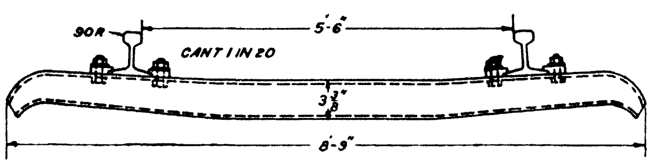


Fig. 309*b*

is slightly opened, the gauge is widened. The widened gauge can be corrected only by inserting a thin piece of metal, called a *liner* or *shim* with the distance piece. In the four-key sleeper, the key on one side of the rail is driven in the opposite direction to the key on the other side and accurate adjustment is possible. On double or multiple line sections, namely where traffic over each track is in one direction only, the two-key type sleepers are laid

in such a way that the thinner end of the key points in the direction of traffic The reason is that any slight movement of the rail under traffic tends to tighten the keys The greatest weakness of key type steel sleepers lies in the lug hole as already mentioned

The *clip bolt type* steel sleeper employs bolts and clips for holding the rail, and, as the holes for the bolts are small and circular, there is little possibility of cracks developing through them By using different sizes of clips, the sleepers may be used for any section of rails and by altering the position of the bolt shanks or *feathers* in the bolt hole, gauge adjustments can be carried out

In order to prevent damage to the edges whilst packing, a bulb is provided along the edges of steel sleepers Clip bolt and four-key type sleepers have an added advantage over other types of sleepers in that they prevent creep (*vide* para 1211) These sleepers are also found to keep excellent gauge

In America, as already mentioned, the type of steel sleepers which has found favour is a steel I beam, about 5′ to 6″ deep and with the top flange 4″ to 5″ wide, the botton flange about 8″ wide, the metal in the web being about ¼″ thick The rails are held by bolts and clips

310. Cast iron sleepers

Cast iron sleepers have been extensively used in India and, on a small scale, in South America. They are hardly used in other

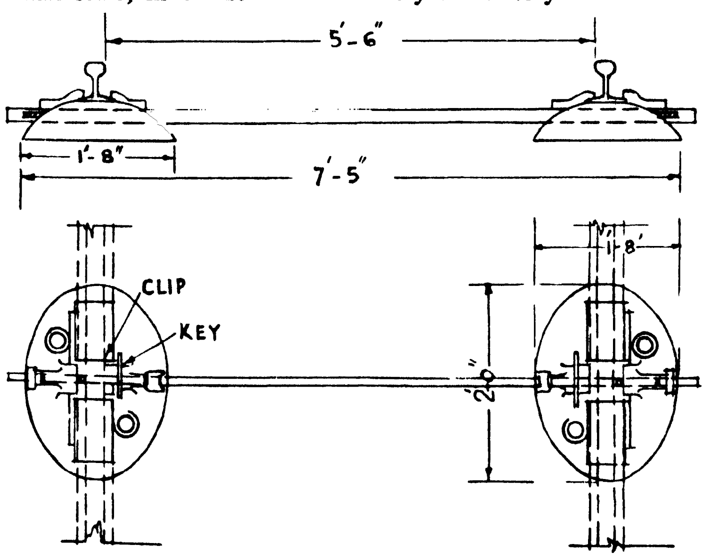


Fig 310*a*

countries. Cast iron sleepers are in the form of pots (Fig. 310*a*) or plates (Fig. 310*b*) with ribs below the plates. Another type, in the form of a box, open on top, in which sand or ballast was filled to make it more stable, has also been used, but is now obsolete. Cast iron sleepers have to fulfil the conditions required of steel sleepers (*vide* para 309) and also an additional condition that the connecting member should be of sufficient strength to maintain the gauge and level of the track. The pots or bowls and the plates are fixed, one under each rail, and are held together with a tie bar. In case of plate sleepers, these tie bars either extend to the outer edges of the pots or plates, or end a little beyond the rail seats. Long tie bars are preferable to short ones as they counteract the tendency of the pots to tilt inwards under loads. The pots are either circular, or oval-shaped, the larger diameter being 2′ and the smaller diameter 1′-8″. The oval shape is better than the round shape as closer spacing, particularly at rail joints, is possible. Two holes are left in each pot for inspection and for packing ballast. The rail seat on the pot consists of a table with a cross slope of 1 in 20. Tie bars are fixed to the pots with various fittings, such as keys (cast iron or steel) and distance pieces, or *gibs* and *cotters*. The cotters are made about $\frac{1}{8}$″ wider at their centre than the gib, so that when the position of the gibs and cotters is interchanged $\frac{1}{8}$″ slack gauge is obtained. By repeating this operation on the opposite pot, $\frac{1}{4}$″ slack gauge is possible. This adjustment is useful for widening gauge on sharp curves.

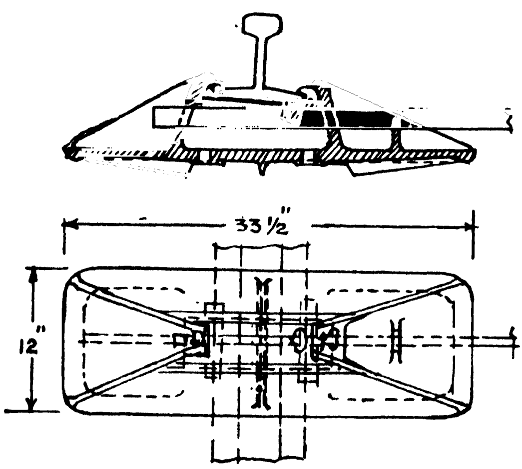


Fig. 310*b*

Plate sleepers consist of rectangular plates about 2′-10″ × 1′-0″, with projecting ribs under the plates for lateral stability. The plates are held in position with tie bars, the connection being similar to that with pots; gibs and cotters, distance pieces and keys or keys alone being used. Both pot and plate sleepers can

be used with flat-footed or bull-headed rails, but they have to be cast accordingly, the jaws forming an integral part of the casting in case of bull-headed rails.

The effective bearing area (*vide* para 303) in both pot and plate sleepers is kept the same as for wooden sleepers, namely, 5 sq. ft. per sleeper or 2½ sq. ft. per each pot or plate on B.G.

One of the disadvantages of not having a rigid connection between the separate supports under each rail, is that it is difficult to maintain uniform gauge due to the slight play between the tie bars and their sockets and also due to the bending of tie bars. The practice of some maintenance men, of deliberately bending the tie bar to correct a wide gauge, is to be deprecated. Slight adjustments in gauge may be obtained by packing the pots or plates along their outer edges if the gauge is slack or along the inner edges if the gauge is tight.

On the other hand, cast iron sleepers have a considerable advantage over all other types of sleepers due to the fact that they possess considerable scrap value. The broken pots and plates can be melted for casting new ones.

Cast iron sleepers require a larger number of fittings than any other type of sleepers and these sleepers are also liable to break, if roughly handled.

Pots made of steel have not been very successful.

The cast iron sleeper currently used is known as the C.S.T.9.

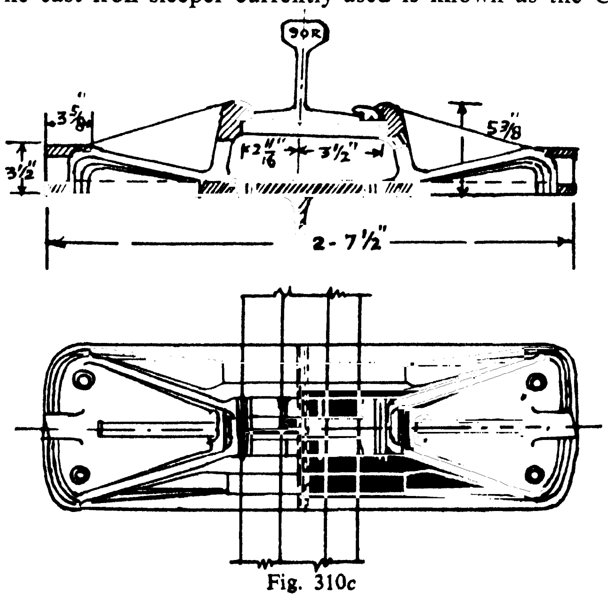


Fig. 310c

sleeper and its behaviour in the track has been very satisfactory. The C S T 9 sleeper (Fig 310*c*) may be described as a combination of plate, pot and box sleeper It has bulbs on either side of the rail seat, a rib under a plate, and the rail is supported on a box. The rails are held to the sleeper with steel keys and, to prevent damage to the cast iron jaw by over driving, light 4-lb. keying hammers are used for driving the keys Two types of tie bars, the short and the long type, are used Inspection holes are provided.

A joint sleeper of cast iron, known as *Rail free Duplex* sleeper (Fig 310*d*), has been used at rail joints in conjunction with C S T 9. sleepers The size of each plate is 2′-9½″×2′-6″ and the plate accommodates the ends of the adjoining rails The rails are not held to the sleeper with any fittings Duplex sleepers give added strength to the rails near the joints

In packing pot or plate sleepers, it is advisable not to pack

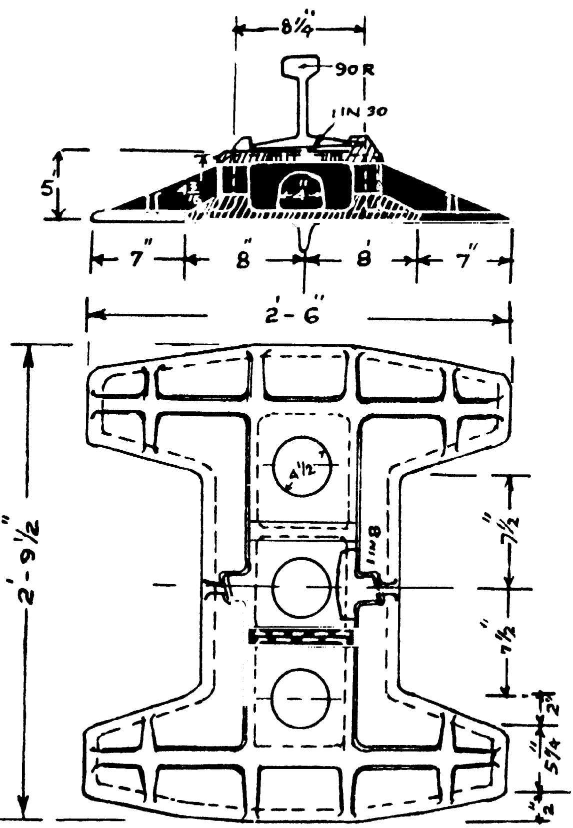


Fig. 310*d*

isolated sleepers. The reason is that it is impossible to pack an isolated sleeper to the exact level of the sleepers on either side of it and the result is that the sleepers on either side are lifted off the ballast. Rough riding is the result and excessive load on the pot or plate, so packed, sometimes damages it. For the same reason, both pots or plates forming a sleeper should be packed at the same time. Random renewals of broken pots or plates also need care in packing and it is better to pack through twice instead of giving one hard packing. Packing of pots is done through the holes provided, but for heavy lifts and in poor soil, the author recommends packing from under the rim of the pot although this means extra work for removing and replacing ballast to the depth of the sleeper. After pot or plate sleepers have been in the track for several years, it is difficult to remove the tie bar from the pot due to corrosion. Cases have been known where a perfectly sound pot has been broken in releasing the tie bar. One method of removing jammed tie bars is to introduce a small screw jack in a frame fixed to the pot and to gently force the tie bar out without damage to the pot.

311. Concrete sleepers

Many types of reinforced and prestressed concrete sleepers have been developed within the last decade in Europe. Experiments have also been conducted in India. Their popularity despite initial setbacks is increasing because of the following reasons, and extensive use of concrete sleepers in India is likely.

Concrete sleepers have a long life which under normal conditions is not likely to be less than 40 years.

Their weight helps considerably in the prevalent tendency to minimise joint maintenance by using long lengths of welded rails. The greater weight confers the advantage of greater stability of track. This increased stability which is good for track with normal rail lengths, becomes essential where rails welded in long lengths are used. The added weight enables the rails to resist effectively forces caused by expansion due to temperature increase which tend to buckle the track.

Concrete sleepers have developed so rapidly that concrete is now considered in some Western countries to be the ideal material for railway sleepers. They are made of a strong homogenous material, impervious to the effects of moisture and unaffected by the chemical attack of atmospheric gases or subsoil salts. It is moulded easily to size and shape required by scientific investigation to withstand the stresses induced by fast and heavy traffic.

The weight of a concrete sleeper is about 2½ to 3 times the weight of a wooden sleeper, and the elastic support given by it to the rails is proportionately greater. It follows that the elastic modulus (*vide* para 1703) of a concrete sleeper track is much higher than that of the wooden or metal sleepered track. A large increase in track modulus completely changes the character, amplitude and the amount of the bending of the track between the wheels of travelling loads and reduces simultaneously the rail and sleeper stresses.

Because of their greater weight, the handling of concrete sleepers is more difficult. The placement of concrete sleepers is however to be viewed as a complete renewal of track in appreciable lengths, using appropriate mechanical devices (Fig. 311*a*). Experience in European countries indicates that this has resulted in overall reduction of cost.

Fig. 311*a*

Concrete sleepers may be broadly divided into reinforced and prestressed types. There are two varieties of reinforced concrete sleepers, namely the through type and the composite block and tie type. The through type reinforced concrete sleeper is not much used because of the following reasons. When the through type concrete sleeper is stressed, cracks on the tension side are inevitable and though the cracks are very small and almost invisible, they tend to enlarge with repetition of the impact loadings of fast trains. Such cracks lead ultimately to the disintegration of concrete and are the main cause of failure of this type of sleepers.

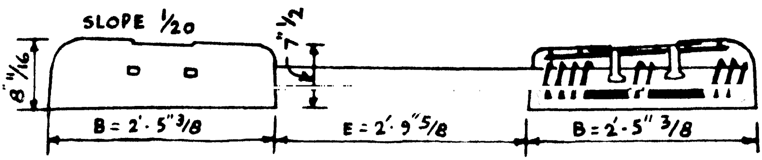


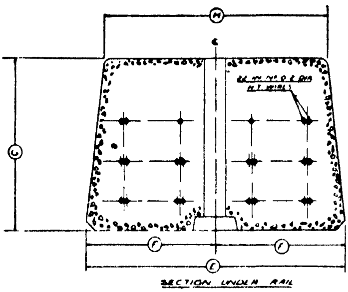
Fig. 311*b*

The composite or block and tie type of sleeper (Fig. 311*b*) is not subjected to the same degree of tensile stress and has given excellent results in France where a steel tie of inverted Tee section is used. Other types of ties have recently been introduced. One consists of a pipe filled with concrete whilst another, the I. D. sleeper, is made of special tough concrete, circular in section and suitably reinforced. Greater rigidity and freedom from corrosion are claimed for the concrete tie.

The disadvantages of the through type of reinforced concrete sleepers have been completely overcome through the application of the principle of prestressing. In prestressed concrete sleepers, the concrete is put under a very high initial compression. This is done by first stretching high tensile wires or rods against some form of anchorage and transferring the pull in the wires or rods to the concrete, after it has set, either through bond or by means of mechanical devices. The wires or rods in tending to shorten to their normal lengths induce compression in concrete. When the sleeper is subjected to the loads of a passing train, the imposed stresses are compression under rail seats and tension in the centre portion of the top surface and reverse stresses on the bottom surface. The imposed compression adds to the compression through prestressing whilst the imposed tension reduces the prestress compression but does not convert it to tension because of the precompression being higher than the imposed tension. Under traffic therefore no tension occurs in any part of the sleeper and therefore no tension cracks develop. Should cracks develop under accidental derailment or similar momentary abnormal conditions, they close and heal up completely on removal of the excess load. The elimination of cracks removes all possibility of deterioration of the sleeper.

Many designs and patent methods of manufacture of prestressed concrete sleepers have been devised in Europe. These have now crystallised into the following three types, two of which are based on pre-tensioning system of prestressing and one on the post-tensioning system. In the first type the sleepers are

manufactured by the long line method of prestressing and the transfer of compressive stress is by bond. A standard gauge sleeper (Fig. 311*c*) 8′-6″ × 10″ × 6½″ weighs approximately 504 pounds and contains 20 pounds of high tensile steel wire about 0′-2″ in diameter. The second pre-tensioned type has a positive anchorage within it, an arrangement which enables compression



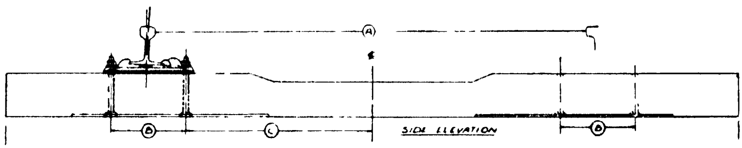


Fig. 311*c*

to be retained in the concrete through a mechanical device in addition to bond.

In the third type (Fig. 311*d*), based on the post-tensioning

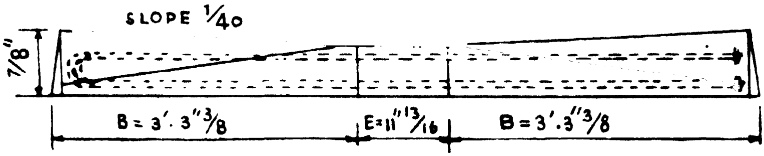


Fig. 311*d*

system, high tensile alloy steel rods are used. The transfer of stress to concrete, after it has attained sufficient strength, is by special nuts at the ends.

The pre-tensioned type of sleepers are mostly used in Britain whilst very large numbers of the post-tensioned variety are laid in Germany.

Special rail fastenings are necessary for concrete sleepers in order (*1*) to prevent deterioration of concrete at the rail seats through continuous pounding, and (*2*) to contain locked up temperature stresses in long welded rails (*vide* para 220). The requirements of a suitable fitting to withstand the pounding are explained in para 512. Devices for holding the rails to concrete sleepers are either elastic or "rigid" and are described in para 511.

Fishplates

401. Rail joints

In order to hold together the adjoining ends of rails in the correct position, both in the horizontal and in the vertical planes, fishplates (Fig. 401) are used. Formerly the ends of two adjoining rails were supported in a heavy cast iron chair; subsequently splices were introduced. These were made of wrought iron and were held with 4 bolts through holes in the splices and rails.

This type is in use even at present, but steel has replaced wrought iron and the sections have been considerably modified. Instead of using separate nuts, tapping of holes in fishplates and treating them as nuts of special shape was tried, but without success. In the modern rail joint, two fishplates are used for each joint and the fishplates are so designed that they fit the underside of the rail head and the top of the rail foot. They are not brought in contact with the web of the rail.

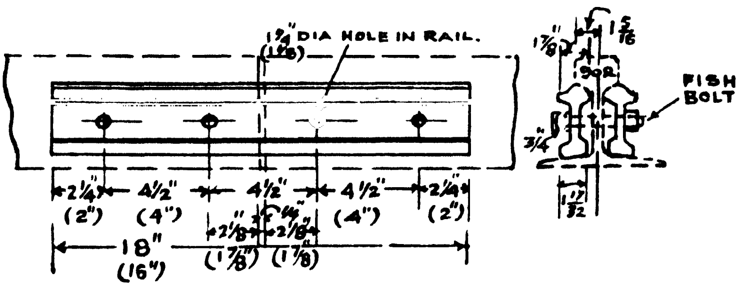


Fig 401

Three types of rail joints are in use In the supported rail joint, the ends of the rails are supported directly on a sleeper An elastic pad is often fixed between the ends of rails and the sleeper to absorb shock If the fishplate is made long enough, about 3′-6″ to 4′ long, three sleepers may be made to support the joint but an objection to such joints is that if the packing of one of the outer sleepers gets loose, undue load is brought on the central sleeper, whilst a loose central sleeper converts the joint into a very weak suspended joint In the suspended joint, which was introduced in 1847, the ends of the rails are suspended between two sleepers and the load at the ends of rails is therefore distributed over two sleepers A third type of rail joint is known as the bridge joint and is similar to the suspended joint, but the foot of the rails at the ends are supported on a bridge or length of metal which rests on the two sleepers With bridge joints, the sleepers at the joint have to be notched to allow the bridge to be fitted, or the joint sleepers have to be laid at a lower level than the remaining sleepers

Various experimental joints are being tried by different railways The Central Argentine Railway uses a tongue joint which removes all rail gaps from the track The tongue joint may be briefly described as a closed switch in which one rail end is tapered to a point and the corresponding rail end of the adjoining rail is splayed like a wing rail and the two ends are bolted together.

A rail joint is considered the weakest part of a track A break occurs at the joint in the continuity of the rails and this introduces a break in the wave caused by rolling loads in the elastic rail. The end of one rail is depressed under the wheel and a blow is given to the end of the adjacent rail when the wheel jumps the gap This blow or shock loosens the ballast and fittings. The result

is that considerable wear of all the materials at the joint takes place. A fishplate has to be so designed as to mitigate this shock. Fishplates must, as already mentioned, hold the ends of the rails in perfect line and also at the correct level. They are made as far as possible of the same strength as the rails they connect. Half the sectional area of the rail for each fishplate would appear reasonable, but as fishplates are not as deep as the rails, much higher stresses are produced in the fishplates when compared to the rails since strength varies as the square of the depth. The deeper rail sections of the present time are useful in enabling fishplates also to be made stronger due to increased depth.

402. Expansion gaps

Expansion gaps are necessary at each rail joint as explained in para 203.

Expansion usually given on Indian railways is as follows:—

Temperature in the sun	Over 70° F.	Over 90° F.	Over 110° F.	Over 130° F.
Expansion gaps with 36′ long rails ..	1/4″	3/16″	1/8″	1/16″

Shade temperatures are normally available and temperatures in the sun may be taken as 30° F. above the shade temperatures. In winter, the temperature in the open may be 10° F. below the shade temperature. The range of temperature in the open in India may be taken as 100° F. in the coastal areas increasing to 120° F. in other areas and reaching a maximum of 130° F. in desert areas.

Expansion gaps adopted in America are as follows :—

Temperature of rail ..	Below 0°	Over 0°	Over 25° F.	Over 50° F.	Over 75° F.	Over 100° F.
Expansion gaps with 39′ rails	3/8″	9/32″	7/32″	1/8″	1/16″	Nil

It may be noted that, whilst in India an expansion gap of 1/16″ is allowed with temperatures over 130° F., no gap is left in America above 100° F.

Fishplates have to be of such a design that whilst they give the maximum support to the rail ends, they at the same time allow

free expansion and contraction of the rails. For this reason, the contact surfaces of fishplates and rails are cleaned and lubricated before the fishplates are fixed and such lubrication is carried out at regular intervals. Fishplates have also to fulfil the condition that the play at the surfaces of contact, due to wear, can be adjusted. Fishplates are held between the bottom of the rail head and top of the rail foot, the surfaces of both these are at a slope and the fishplate is not in contact with the web of the rail, hence by tightening the bolts, wear is taken up as the top and bottom contact surfaces form a wedge. The slope of the surface of contact under the rail head is an important item and this slope is made as flat as possible to ensure good contact. In India, a slope of 1 in 4 is adopted, whilst in America it is 1 in 4⅛.

403. Different types of fishplates

A great variety of shapes and sections are employed for fishplates. They may consist of flat bars, or angles or bars with ribs (Fig. 401). For increasing their strength, deeper fishplates have been provided in case of B.H. rails. The increased depth is obtained by extending the plate below the lower table of the B.H. rail after kinking it near its lower contact surface in order to clear the width of the lower table. With F.F. rails, an angle section has often been used. Fishplates of angle section or with projections or ribs are more satisfactory as bar fishplates bend laterally, allowing the rail head to deflect in the horizontal plane. Various modifications of the angle sections have been adopted in America, one of which is shown in Fig. 403. The shape standardised in India is that shown in Fig. 401 and the dimensions given are for use with 90-lb. rails. Figures in brackets are for 60-lb. rails. These fishplates vary in length from 14″ to 18″ depending on the section of the rail used. Fishplates used in America are either 24″ long with four holes or 36″ long with six holes.

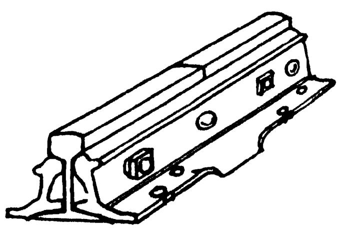


Fig. 403

Fishplates have been tried, in which the surfaces of contact do not extend throughout the length of the fishplates but are provided only at the middle and at the two ends of the plates. Another type is known as anti-impact fishplate. It is considerably

thicker and deeper in the middle than at the ends and the contact surfaces are only along the central thickened portion. This minimises wear of the contact surfaces and the resultant impact due to the play caused by wear. These fishplates are expensive as they are not rolled but are forged.

Where track circuits exist, the two ends of the rails are connected with wires, known as bonds, to allow a path for the small electric current which passes through the rail. With joints situated on track-circuited lengths, fishplates require to have a slightly modified shape to accommodate these bond wires. Also at certain joints, the fishplates and fishbolts have to be insulated and for this a layer of special insulation material is interposed between the fishplates and the rails and insulation tubes are introduced round the fishbolts.

404. Details and maintenance of fishplates

Fishplates are usually provided with four holes and the length generally does not exceed 18″ in India and 24″ in America. Longer fishplates with six holes have been tried on the assumption that a longer support at the rail head produces a better joint. Fishplates with five holes had also been used to a limited extent in India, semi-circular notches being cut at the end of the rails in the web to accommodate the central bolt. At a later stage the central bolt was omitted. In Britain, two-holed fishplates have been used in large numbers and in India, experiments had been carried out with 9″ long fishplates, but the four-holed fishplates are likely to remain the general standard.

Opinion varies in America as to the length of the fishplates. On one hand, it is considered that, however long a fishplate may be, only the central 14″ or so are effective. On the other hand, a Committee of the Roadmasters' Association advocated in 1948, 36″ fishplates for the revised 112-lb. and 131-lb. rail sections. Their contention was that joint maintenance was reduced with longer fishplates. Other variations in American fishplates design are, (*1*) reduction in the lateral stiffness of the head with the intention of deflecting the fishplates through bolt tension to take up wear, (*2*) bringing the web of the fishplate close to the rail web to reduce bolt breakage, and (*3*) reducing the thickness of fishplate web to secure "springiness" in the vertical direction and to maintain bolt tension.

Bolt holes in fishplates act as stress raisers and experiments in America have indicated stresses near bolt holes three times the stress elsewhere in the web. An increase in the distance between

the end of the fishplate and the nearest bolt hole is found to reduce the stresses near bolt holes.

Due to vibration, fishplates are apt to get loose and unless immediately tightened, considerable wear occurs at the contact surfaces of rails and fishplates. Lock nuts or spring washers with ordinary nuts are often used to prevent the bolts from getting loose. Again, to prevent the bolts from getting loose long nuts are used the length of the nut being made $1\frac{1}{4}$ to $1\frac{1}{2}$ times the diameter of the bolt. The holes for bolts are generally $4\frac{1}{4}''$ apart in India and $5\frac{1}{2}''$ apart in America. The diameter of the holes in the fishplates are kept $\frac{1}{16}''$ larger than the diameter of the bolt to be fitted. The diameter of the corresponding holes in rails are kept $\frac{1}{4}''$ larger to allow for expansion and contraction. Holes of oval shape have also been made in rails for the same reason. In America, the bolts are provided with a feather on the shank just under the bolt head. These feathers fit into pear-shaped holes in the fishplate and prevent the bolt from turning whilst tightening the nut.

In the angle type fishplates, notches are sometimes cut in the horizontal arm of the angle to accommodate heads of spikes driven into the sleepers, as a precaution against creep. This device is not sufficient to prevent creep, when it is excessive, and the sleeper is pushed out of position.

Certain precautions are necessary when fixing fishplates at joints. The contact surfaces should be thoroughly cleaned and oiled, as wear is increased if any foreign matter is left and friction of unoiled surfaces prevents expansion and contraction of rails. When tightening the fishbolt in angle type fishplates, the plates should be tapped at the base to obtain a snug fit, as such plates have a tendency to remain splayed out. The two central bolts should be tightened first and all the bolts should not be tightened to such an extent as to damage the bolts. The length of the spanner is limited for this purpose and the spanner should not be lengthened by slipping a piece of pipe over the handle. When the bolts are new, they need tightening more often as the bolts in the initial stages get loose. If a joint is to be kept in good condition, fishplates must fit properly and there should be correct tension in fishbolts.

Care is to be exercised in maintaining the correct expansion gaps as given in para 402. If the expansion is insufficient, the ends of rails get jammed in the hot weather and prevention of further expansion may cause high compressive stresses in the rail resulting in the track being pushed out sideways. This is called "buckling," and trains have been derailed with serious consequences due to it. On the other hand, too large a gap may lead, particularly in

severe cold, to the distortion of fishbolts and even to the breaking of fishplates. The danger of buckling is enhanced by creep and this subject has been dealt with in para 1311.

The failure of a fishplate usually begins with a crack at the top centre or the bottom centre. A crack at the bottom is the result of excessive bending of the rail joint due to a combination of wear in the contact surfaces, loose sleepers, battered rails, etc. A crack at the top may be due to one of the two joint sleepers being very loose. The wheels, when they jump on to the rail supported by a loose sleeper, bend the fishplates in the direction opposite to normal direction and this is liable to start a crack at the top.

Some of the methods by which the weakness of rail joints is reduced, have already been mentioned in Chapters 2 and 3. Close spacing of joint sleepers, use of special joint sleepers, elimination of as many joints as possible by welding, are some of the methods adopted, apart from the improvement in the design of fishplates.

405. Liners or shims and reconditioning of fishplates

Due to the heavy duty to which fishplates are subjected and, sometimes due to poor maintenance, the contact surfaces of fishplates get considerably worn. As wear of contact surfaces means looseness between rails and fishplates, the situation is further aggravated. To remedy this defect, *liners* or *shims* are introduced at the contact surfaces. These may consist of strips of steel of the required thickness, say $\frac{1}{32}''$ to $\frac{1}{8}''$, and may be made locally out of hoop or flat iron. The clearance between the contact surfaces must be carefully measured and liners of the correct thickness inserted, otherwise they are likely to do more harm than good. Such liners are likely to work loose duc to vibration if they are of insufficient thickness or if the fishbolts have become loose. The wear on contact surfaces of fishplates and rails is not uniform, the greatest wear being at the extreme end of the rail and a ridge is left on the fishplate at the expansion gap. Flat liners, therefore, do not produce uniform bearing and wedge-shaped liners, with either a gap in the middle to avoid the ridge in the fishplates or in two pieces, are much more effective, These liners have an extension with a notch to fit the fishbolts. Due to their being held by fishbolts, they do not move out of position even if the latter get loose. In order to determine the thickness of the liner, a steel straight edge of the length of the fishplate is placed on the head of the rail. Spaces between the straight edge and the rails and between the contact surfaces of the rail and fishplate are then measured with a graduated wedge or with strips of known thickness.

Another method of taking up the wear at the contact surface is to replace the worn fishplates with others which are slightly deeper.

A third method of improving rail joints is to recondition the fishplates. The fishplates are removed, made slightly deeper at the centre by hot pressing, the contact surfaces are machined and the fishplates heat-treated. Reconditioned fishplates are known to give excellent results. As the wear is not uniform at all joints and it is not economical to arrange for varying depths, some of the reconditioned fishplates of the bar type, when fitted, are found to bulge a little at the centre. This bulge disappears with a little wear at the contact surfaces.

406. Junction fishplates

When rails of different sections have to be joined together, special fishplates have to be used. These are variously known as *junction*, *compound*, *combination* or *cranked* fishplates or *compromise joints*. Each half is made to fit two different sections for which the fishplate is meant. In the Indian standard design, the fishplates are made thicker at the centre than at the ends and the outer fishplates are made $\frac{1}{4}''$ thicker than the inner fishplates. Due to these variations all the four fishplates at a junction are different and in order to differentiate these, they are designated left inside, left outside, right inside and right outside, the direction being that obtained by facing the heavier rail. In America, tapered rails of short lengths are sometimes used. The section at each end of the tapered rail corresponds with the sections to be connected, and the rails are tapered on all surfaces except the top surface.

407. Expansion joints

Expansion joints required with long welded rails are indicated in para 220.

Special expansion joints are also used on long steel girder bridges. On bridges of long spans the girders expand and contract an appreciable amount. The rails, if they are rigidly attached to the structure, expand the same amount as the girders. Even if the rails are not rigidly attached, it is customary to weld together the rails on each span and introduce the necessary expansion gaps at the ends of the span. Special expansion joints are used for this purpose. The ends of the rails are either recessed or mitred, namely, cut at an angle of 45° so that each recessed or mitred end overlaps a similarly shaped end of the adjoining rail. Special fishplates about $2'$-$2\frac{1}{2}''$ long are used, the inner fishplate is similar in section

to the standard fishplates but the outer fishplate has a thick arm projecting upward and flush with the rail head. The holes in the fishplates are slotted and may be $2\frac{1}{4}''$ long. As $1''$ diameter bolts are used, each rail can move $1\frac{1}{4}''$ and the maximum gap which may be obtained is therefore $2\frac{1}{2}''$.

408. Staggering joints on curves

When rail joints on curves are kept square, namely, when a joint on one rail is exactly opposite the joint on the parallel rail, there is a tendency for shoulders or kinks to form at the joints. The reason is that due to the inherent weakness at the joint, the centrifugal force tends to push the track out more at the joint than elsewhere. The rails also form shoulders at the joints due to their tendency to spring back from their curved position. To lessen this tendency it is common practice to stagger joints on curves. The joint on one rail is kept facing the centre of the opposite rail. This arrangement not only reduces the possibilities of shoulders or kinks at joints, but also reduces the vertical movement of the wheels at the joints. With staggered rails, the number of hammer blows at joints are doubled but their intensity is halved. The number of sleepers is also increased by one.

409. Staggering joints on straight track

In order to secure, on straight tracks, the advantages of staggered joints, short staggering of joints has been tried out in India. In the *short stagger*, the joints on the opposite rails are kept a few inches out of square. In America all joints, both on curves and on straights, are staggered, the *long stagger* being used in all cases, namely, each joint is opposite the centre of the opposite rail.

The advantages claimed for short-staggered joints are (*1*) avoidance of two weak spots, namely the joint, directly opposite each other, (*2*) reduction of impact at joint by half, although the number of impacts is doubled, (*3*) production of a more uniform vertical continuity of track. Short stagger of joints, however, results in bunching of sleepers with resultant variation in the elastic modulus of track. This difficulty has been met in the cast iron plate sleeper by keeping the plates on either side of the joint at 1′-3″ centres and connecting a plate on the opposite rail by a Y-shaped tie bar, the normal spacing of the plates being thus retained on the opposite rail.

CHAPTER 5

Track Fittings

501. Fishbolts, nuts and locking devices

WITH each pair of fishplates two, four or six fishbolts are used. The standard practice is to use four bolts. As the fishbolts have to withstand considerable stresses in developing the full transverse strength of the fishplate, they are made of medium or high carbon steel and of large diameter (Fig. 501). They vary usually from $\frac{3}{4}''$ to $1\frac{1}{8}''$ dia., $1''$ dia. being suitable for 90-lb. rails and $\frac{7}{8}''$ for 60-lb. rails. A large diameter is also necessary to withstand stretching when unnecessarily long spanners are used. The length of a spanner is invariably fixed, but when bolts continue

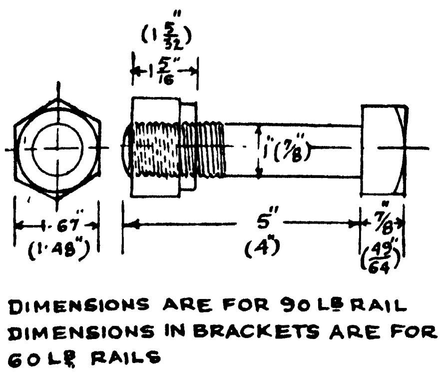


Fig. 501

to get loose, maintenance men are inclined to lengthen the spanners. Overtightening jams the fishplates with the rails and prevents expansion and contraction. It is good practice to loosen the nut by a quarter turn after thoroughly tightening the bolt with a spanner of correct length. The length of the bolt depends upon the shape and thickness of fishplate and on the length of the nut; a projection of about ¼" of the shank is left after the nut is tightened. Nuts are made of sufficient length to provide a good grip on the bolt and are either of square or hexagonal shape. In America, a neck of oval or square shape is formed on the shank just under the head and this fits into a corresponding hole in the fishplate. The neck prevents the bolt from turning due to vibration and as the head of the bolt is generally circular in that country the neck also prevents the bolt from turning whilst being tightened. In India bolts have square heads which can be held by a second spanner. In practice, a second spanner is dispensed with by putting a wedge consisting mostly of a dogspike, between the bolt head and the foot of the rail. Recesses in the fishplates to house the neck weakens the fishplate and if square recesses are provided, cracks are likely to start at the corners. To prevent the bolts from turning due to vibration, nuts or spring washers are often provided, particularly on tracks carrying high speed traffic. Heat treatment of bolts helps in preventing loosening of the bolts. Lock nuts are of various types, a common type being one in which the threads in half the length of the nut are deeper than the corresponding threads on the bolt. This half of the nut also has a number of slits parallel to the axis. When the nut is turned on the bolt, the segments in the portion with the deeper threads is forced slightly open. As the segments have a tendency to return to their original shape they have a firm grip on the bolt. Spring washers, of helical or any other shape, due to their tendency to spring open, prevent the nuts from moving. Spring washers of alloy steel are also used. Plain washers are not generally used with fishbolts but the nut

is sometimes made circular where it comes in contact with the fishplate (*vide* Fig. 501).

Unless periodically cleaned and oiled, the nuts cannot be removed due to rust. Most railways have a regular programme for this work. The contact surfaces of fishplates are also lubricated at the same time.

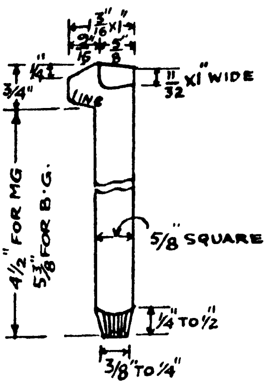


Fig. 502

502. Dogspikes

For holding the rail to wooden sleepers, spikes of various types are used. The spike most commonly employed is $\frac{5}{8}''$ square and varies in length; it is $4\frac{1}{2}''$ long for M.G. and $5\frac{3}{8}''$ for B.G. Lugs are provided in the head for extraction and the spike is known as a dogspike due to the shape of its head (Fig. 502). The other end is either blunt, pointed or chisel shaped. The spike has smooth sides and depends for its holding power on the friction of the wood fibre. In America the head is a little wider and flatter than in India. A dogspike can stand an initial pull of nearly two tons, but after it has started moving, a very much smaller pull is needed to extract it. Spikes with jagged sides have been found to possess less holding power as the fibres are badly torn and friction is reduced. Experiments in America have shown that a pointed spike has the best holding power, a blunt-ended spike comes next. Chisel shaped ends have poor holding power as they crush the fibres when being driven. It was also found that for the same reason, spikes in bored holes had greater holding power than those driven without boring holes. Although the dogspike has less than half the holding power of a screw spike (para 503), it is used far more than the screw spike because it is cheaper, holds the gauge better and is easily fixed and removed. Four spikes are usually fixed per sleeper, one on each side of each rail, but in tracks with heavy traffic at high speed, the number is increased to six or eight; two spikes being fixed on the outside of each rail and one or two on the inside of each rail. Six to eight spikes per sleeper are particularly used on curves to counteract the greater side thrust. The four spikes in a normal track are not fixed in one line in the sleeper, as this is likely to split the sleeper, but the spikes are staggered, the two outer spikes being in one line and the two inner ones in another line. If an outer spike was kept in line with

the inner spike of the opposite rail, the sleeper would not remain square to the rails but would have a tendency to move out of position and the gauge would hereby be altered.

For fixing spikes, holes are bored with augers. the hole bored being slightly smaller than the section of the spike. It is better to bore the hole right through the sleeper instead of stopping short of the bottom of the sleeper. Accurate boring is essential as incorrect boring affects the gauge. The spike is also to be driven vertically and with the shank touching the edge of the rail foot; if the spike is not driven absolutely vertical, a slight play remains between the rail edge and the shank, the gauge alters, the hole is widened and moisture entering the hole decays the sleeper The wave motion of the rail pulls up the spike slightly. If the head is not pulled up more than about $\frac{1}{16}''$ to $\frac{1}{8}''$, the spike should not be driven back as constant driving loosens the spike by polishing the sides of the spike hole. When a spike becomes too loose, it is pulled out, the hole is plugged with a wooden plug, another hole is bored and the spike redriven. After this operation is repeated a number of times, the sleeper has to be renewed. Such sleepers are called *spike killed* sleepers. It is essential that a full plug should be inserted in the spike hole which is to be plugged. Filling the hole with chips of wood or driving chips with the dogspike in the same hole are useless operations.

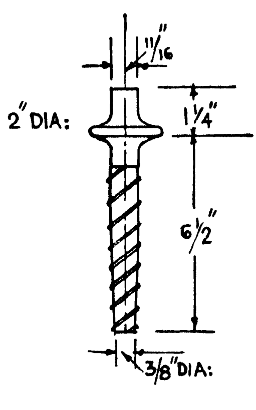


Fig. 503

503. Screw spikes

Screw spikes or *coach screws*, as they are sometimes called, are slightly tapered spikes which, for B.G. are $6\frac{1}{2}''$ long, about $\frac{3}{4}''$ diameter under the head and about $\frac{5}{8}''$ diameter at the end with a special thread of $\frac{1}{2}''$ pitch (Fig. 503). The head is circular and about $2''$ diameter with a $\frac{3}{4}''$ square projection on the top. The American screw spike for $4'$-$8\frac{1}{2}''$ gauge is of almost the same dimensions, being $6''$ long with a head $2\frac{1}{4}''$ diameter and a projection $1''$ square. A box spanner fits on the projection on the head and turns the spike. This projection is slightly tapered. A point is often left on top as a precaution against hammering of these spikes.

Screw spikes have a much greater holding power than dogspikes, the value being almost double that of dogspikes. They

also stand the lateral thrust better than dogspikes, but they are costlier.

Screw spikes do not destroy sleepers by spike killing. Holes are bored of a diameter equal to that of the spike at the base of the thread. The spike is not screwed home, but is left slightly above the rail foot to make allowances for the wave motion in the rails. In America screw spikes are often used with bearing plates having special shoulders to accommodate the spike heads. If gauge is to be corrected where screw spikes exist, the process is not so easy as with dogspikes.

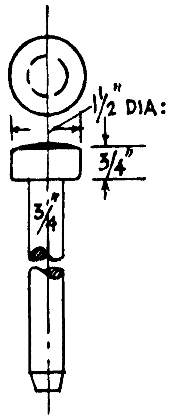


Fig. 504

504. Round spikes

Round spikes (Fig. 504), which are normally $\frac{3}{4}''$ in diameter with a $1\frac{1}{2}''$ diameter head, either cylindrical or hemispherical, are used for fixing chairs of B.H. rails to wooden sleepers and for fixing slide chairs of points and crossings. The length varies according to the gauge of the track and the spikes have a blunt end. Their use is limited.

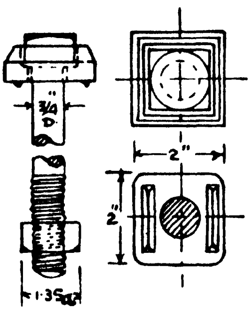


Fig. 505

505. Fang bolts

Fang bolts (Fig. 505) are used for the same purpose as round spikes. The fang or square nut, with special projection to grip the sleepers from the bottom, is about 2″ square and the bolts are made $\frac{3}{4}''$ in diameter and of sufficient length to pass through the sleeper and the chair and have a projection for the nut. Fang bolts are not much used due to the difficulty of fixing and removing them. *Wooden keys* or *trenails* are used in Britain in conjunction with fang bolts; two holes in a rail chair are fitted with fang bolts and the remaining two with wooden keys. These trenails are supposed to prevent rattling as the holes in a cast iron chair cannot be made to fit the fang bolts exactly.

506. Fittings for steel trough and cast iron plate and pot sleepers

The fittings employed with steel trough and cast iron plate and

pot sleepers are numerous and each type of sleeper has different types of fittings.

With steel sleepers, tapering wedges or *keys* $7\frac{1}{2}''$ to $10''$ long and *distance pieces* are used. They are of various sections.

Loose jaws (Fig. 506*a*) in conjunction with keys form very

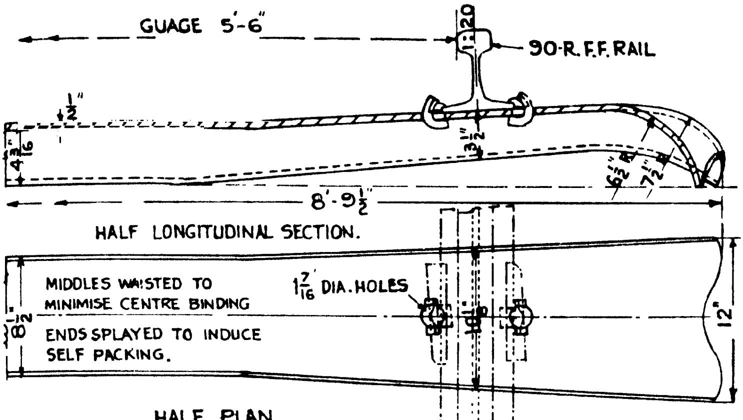


Fig. 506*a*

satisfactory fitting for steel sleepers. The loose jaws are inserted in holes left in the sleeper and overcome the trouble of torn lugs in steel sleepers.

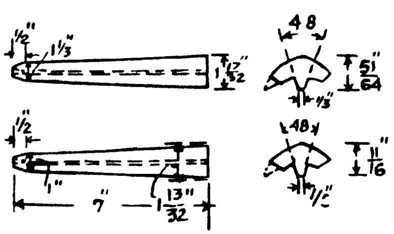


Fig. 506*b*

Two-way keys used with four-key steel sleepers are shown in Fig. 506*b*. *Clips and bolts* used with sleepers are shown in Fig. 309*b*.

The key used with cast iron plate sleeper is shown in Fig. 310*b* whilst the key used with the C.S.T.9 sleeper is visible in Fig. 310*c*. Fig. 310*a* shows not only the key but also the *gib* and *cotter* which are used for connecting the plates or pots to the tie bar. The gib is a rectangular piece of metal with a recess, whilst the cotter is a wedge-shaped piece of metal.

507. Chairs and chair keys

Whilst F.F. rails can be fixed directly to sleepers, D.H. rails require chairs to hold them. The chair also distributes the load from the rail to the sleeper. It is invariably made of cast iron and

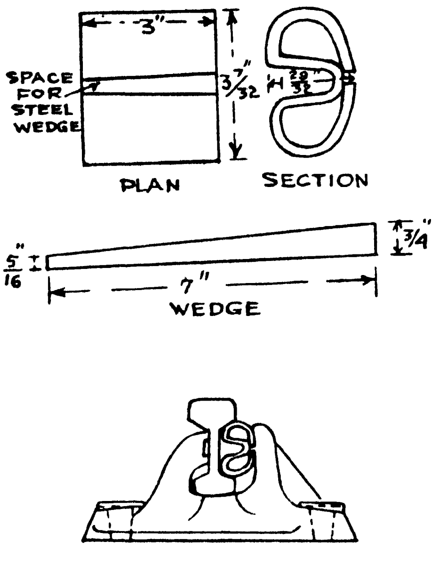


Fig. 507

has two jaws sufficiently wide apart for the rail to be placed in the chair without tilting (Fig. 507). The lower table of the B.H. rail rests on the base of the chair. The web of the rail fits against one jaw and a key is inserted between the opposite face of the web and the second jaw. Jaws are either straight or tapered on the inside face and when they are tapered the chairs have to be classed as right hand or left hand. Tapered jaws with appropriate keys are a precaution against creep. The chairs have mostly two and sometimes three or four holes, and the minimum weight of each chair specified in Britain is 45 lbs. The keys are fixed either against the inner or the outer jaw. Former practice was to fix the keys against the inner jaw on the assumption that in case the keys fell out, the gauge would not get wide. Keys fitted against the inner jaw however get loose sooner than those fitted against the outer jaw. Also a key in this position reduces vibration by acting as a cushion against the side thrust of the wheel. Keys are either of wood or of metal and are straight or tapered. A typical section of a wooden key is $3\frac{3}{8}'' \times 1\frac{5}{8}''$ tapering by $\frac{3}{8}''$ on both faces. Wooden keys are liable to attack by vermin and to theft; they also get loose in a hot, dry climate. In Britain wooden keys are usually made of oak and are compressed before use. In India metal keys of various designs are favoured. Keys in the shape of closely coiled springs and in several other forms are available. The Stewart key is a steel plate bent in the form of an E (Fig. 507). In the space between the ends of the metal, a wedge-shaped piece is driven. This keeps the key tight against the rail web and the jaw of the chair.

The chairs have to be fixed on a level base on the sleeper, otherwise the chairs are liable to break due to loads being concentrated on a small area instead of being uniformly distributed.

When D.H. rails are used with cast iron sleepers, either of the pot or the plate type, the jaws are cast with the pot or plate. The shape of the jaws is similar to that of the chair for wooden sleepers. With steel trough sleepers, chairs are riveted to the troughs.

508. Bearing plates

In order to protect wooden sleepers from injury by F.F. rails under heavy loads, bearing plates are interposed between the foot of the rail and the sleepers. Bearing plates are made of mild steel, cast iron, wrought iron, or malleable steel. They may be plain rectangular plates with holes for spikes or they may be of an elaborate design. Bearing plates are required not only to distribute the load but to reduce the rubbing action of the rail seat on the sleeper. This action is reduced when the area over which it takes place is increased. American practice in working out load distribution is to assume that the axle load is distributed over three adjacent sleepers. This assumption is presumably governed by the very close spacing of sleepers adopted there. In India as well as on some railways in America, the middle sleeper is assumed as taking 50% of the axle load and the sleepers on either side as bearing 25% each of the load. Bearing plates are mostly used on tracks which carry heavy vehicles at high speeds. They are not as necessary with hard-wood sleepers as with soft-wood sleepers and particularly with treated sleepers. As a combination of these three conditions, namely, heavy vehicles, high speed, and treated soft-wood sleepers exists in America, bearing plates are used extensively in that country. In India, on account of the greater use of hard-wood sleepers, bearing plates are generally fitted in special places such as at rail joints, on curves, on bridges, on ashpits where expensive timber of large dimensions is used, and under points and crossings. Bearing plates used under points and crossings have to be of various shapes and sizes to accommodate combinations of rails and also to enable the sliding of *tongue rails*.

Rails on curves have a tendency to overturn due to the heavy outward thrust. The pressure is also concentrated at the outer edge of the foot of the rail on account of the same outward thrust resulting in the outer edge of the rail foot cutting into the sleeper. The bearing plate prevents this by distributing the edge load and the inner spike helps in bearing part of the outward thrust because the bearing plate forms a connecting link between the inner and the outer spikes. For the same reason, better gauge is maintained on tracks having bearing plates.

Cast iron bearing plates are heavier than steel bearing plates and are liable to be damaged particularly by derailed wheels.

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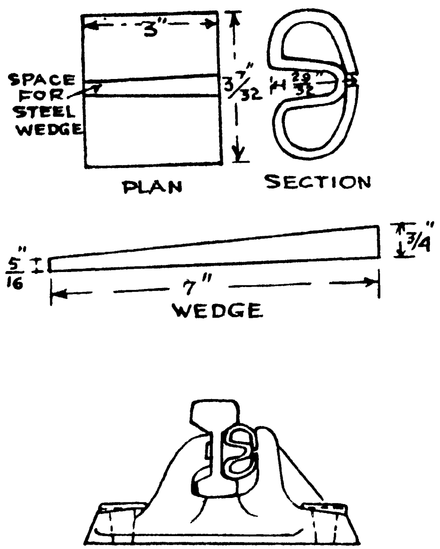

Fig. 507

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Cast iron bearing plates are heavier than steel bearing plates and are liable to be damaged particularly by derailed wheels.

They are however cheaper. On the other hand, steel bearing plates are easier to fit.

The steel bearing plate (Fig. 508) used in India is 9" long (in the direction paralled to the rail), 10" wide (at right angles to the rail), and $\frac{3}{8}$" thick. It weighs 13$\frac{3}{4}$ lbs. These dimensions and weight are for a B.G. bearing plate, the corresponding figures for a M.G. bearing plate are 6$\frac{1}{2}$"$\times$8"$\times\frac{3}{8}$" and the approximate weight 9 lbs. In America the width varies from 9" to 12", the length being 7" and above, and the thickness $\frac{3}{8}$" to $\frac{3}{4}$".

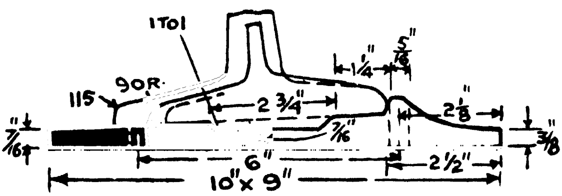


Fig. 508

The area of the bearing plate beyond the inner rail space is kept larger than the area in the inner rail space. Spike holes are made $\frac{1}{8}$" larger than the spikes. Bearing plates in India have a smooth base whilst those in America have either a smooth base or a base with serrations not more than $\frac{1}{4}$" deep and of various designs, from straight lines to herringbone and check patterns. In India the rail bearing surface has a central recess, whilst in America this surface is either smooth or humped. Bearing surfaces are invariably canted at 1 in 20. This obviates adzing of sleepers to obtain the required tilt in the rail. The Americans also provide single or double shoulders on the top surface to hold the edges of the rail foot. With a single shoulder on the outer side it is possible to use rails of varying sections; this is not possible with double shoulders. On the other hand, double shoulders minimise creep due to a better grip on the rail foot. The shoulder is made sufficiently low to allow the spike head to grip the foot of the rail. The standard cast iron four-holed bearing plate in India, for B.G. is 8" long$\times$11$\frac{1}{4}$" wide$\times$ $\frac{1}{2}$" thick at the edge and has a minimum thickness of 1$\frac{1}{8}$" at rail seat, which has a slope of 1 in 20. A shoulder is kept on the outside edge of the rail.

Bearing plates have to be made as short as possible consistent with adequate distribution of load, since long bearing plates are

liable to tilt due to the sudden pressure brought on the receiving edge of the plate. This causes rocking of sleepers. To overcome this tendency, bearing plates are humped, either by cambering or by crowning. A *cambered plate* is one in which both the top and bottom surfaces are parallel and slightly raised at the centre by bending. A *crowned plate* has a similar convex surface on the top but is flat at the bottom. Tilting of bearing plates also loosens the spikes and this in turn allows the rails to creep; this is another reason for keeping the bearing plates reasonably short. Sleepers are sometimes found worn under the bearing plates, but this wear is due not so much to crushing by heavy loads as to abrasion of loose or improperly fitted bearing plates. To prevent looseness caused by the pulling up of spike heads on account of the wave motion in the rails, fittings holding the bearing plate separately to the sleeper would appear to be desirable, if one of the main objects of a bearing plate, namely, prevention of the destruction of sleeper at the rail seat by rubbing action of the rail, is to be achieved.

With the use of concrete sleepers on an increasing scale the introduction of a resilient pad or soleplate (*vide* para 513) between the rail and the concrete sleeper has become of importance.

509. Fittings for rails on bridges, ashpits, etc.

The track is carried over bridges either (*1*) on ballast spread on the deck of the bridge or (*2*) on sleepers fixed directly on the girders or (*3*) the rails are fitted without sleepers to the girders.

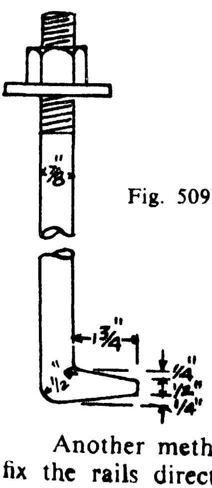


Fig. 509

In the first case, no special fittings are required and the riding qualities of the track are not changed. When sleepers rest on girders, the rails are fixed to the sleepers with standard dogspikes or screw spikes and the sleepers are fastened to the girders separately with bolts having a special head (Fig. 509). The heads of these *hookbolts* or *dog bolts* grip the flange of the girder and are threaded through holes bored in the sleepers. Two hookbolts are sufficient for each sleeper. Bearing plates are invariably used on bridges.

Another method is to eliminate sleepers from bridges and to fix the rails direct to the steel girders. The advantages of this method lie (*1*) in the saving of sleepers and their maintenance, (*2*) in reduced weight on girders, particularly when compared

with the weight on bridges with decked and ballasted floors, and (*3*) in more head room. The drawbacks of direct connection of rails to girders consist of the change in the riding quality of the track over the bridge, and the difficulty of adjusting track levels and grades.

When rails are fixed direct to girders, clips and bolts are used as fastenings.

On ashpits and examination pits, rails are either (*1*) fitted to baulks of timber, about 12″×8″, parallel to and under the rails, or (*2*) fixed to concrete sections of a similar size with bolts and clips, the bolts being built in the concrete, or (*3*) steel or cast iron joints or channels are laid under the rails and the rails are held with clips and bolts. This last method is used in America. The timbers in the first method are held to the masonry with *holding down bolts* which are passed through suitable holes left in the masonry, the nuts being accommodated in niches in the masonry and the bolt heads being countersunk in the timber. Another method of fixing the timbers is to embed *Lewis* or *rag bolts* in the masonry and countersink the nuts in the timber. Timbers about 16″×8″ are also held to the masonry with approximately 6″×4″ angle irons fixed on either side of the timber, screws being used for attaching one arm of the angle iron to the timber and bolts being employed for fixing the other arm to the masonry.

A cheap and effective method is to bury in an inverted position the head and web of used rails in concrete and to fix the running rail direct to the foot of such inverted rails.

510. Check rails

Check rails or *guard rails* (Fig. 510*a*) are lengths of rails, or other shapes of rolled sections, attached to the running rails.

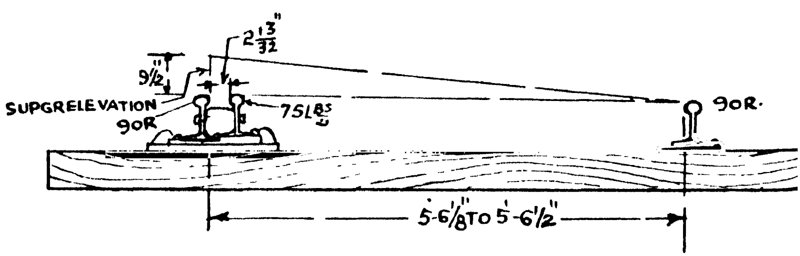


Fig. 510*a*

They are used (*1*) with points and crossings, (*2*) on sharp curves,

(*3*) on roads crossing the track at rail level, (*4*) on large girder bridges with open floor, and (*5*) where a derailment would produce serious results, e.g. when there is a retaining wall on one side of the track or when the track is very close to projecting rocks. At points and crossings and on curves, these subsidiary rails are known as check rails and when fixed on bridges and level crossings, they are usually called guard rails. Check rails and sometimes guard rails are held to F.F. running rails with bolts through distance pieces of cast iron, known as *check blocks*. The size of the check block gives the requisite clearance. The foot of the check rail is planed on one side to enable the required clearance to be obtained. Check rails are also flared at the ends to prevent the wheel flange from striking them. With B.H. rails, special chairs in the form of double chairs are used (Fig. 510*b*), the central casting being made to give the exact clearance. The various uses of check and guard rails are described below.

(*1*) When rails of different tracks cross one another (*vide* Chapter 7) spaces have to be left, at the crossings, in the head of each rail to allow the wheel flanges to pass. In order to guide the wheel flanges in the correct spaces and prevent them from taking the wrong track, *check rails* are fitted to the opposite rails of each track. Check rails are sometimes fixed immediately in front of the points or switches particularly when they are on curves, to protect the switches from rapid wear due to grinding of wheel flanges against them. Elaborate fittings and special cast manganese one-piece check rails are often used in America.

(*2*) *Check rails* are provided along the inside edge of the inner rail of a curve to counteract the tendency of the wheels to rub against the outer rail due to centrifugal force. Centrifugal force increases with the speed and the sharpness of the curve and the wear increases correspondingly. Uneven loading of vehicles, worn wheel flanges, long wheel base of locomotives and insufficient superelevation on sharp curves may even result in the derailment of vehicles moving at high speed if check rails are not provided. Check rails are fitted to the inner rail at such a distance that the flange of the wheel on the outer rail is prevented from coming in contact with the outer rail due to the inner face of the opposite wheel rubbing against the check rails. Check rails are not required on all curves but only on sharp curves and the degree of curve above which check rails are required is determined by the wheel base of the locomotives and the anticipated

speed. In India, check rails are essential with curves of 8° and over for B.G., 14° for M.G. and 40° for N.G. Check rails however are fitted to flatter curves also. They are desirable at the junction of *reverse curves,* namely, a track curving to the right followed by a curve to the left or *vice versa.* Check rails also help in supporting flangeless driving wheels on curves if such

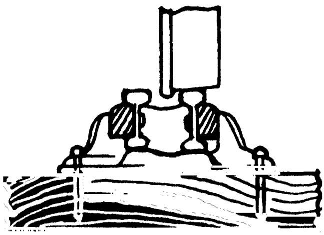


Fig. 510*b*

wheels are provided on locomotives. In Britain, check rails are often used with curves of approximately $4\frac{1}{2}$°. The minimum clearance between the running and the check rails is $1\frac{3}{4}''$ for B.G., $1\frac{5}{8}''$ for M.G. and $1\frac{7}{16}''$ for N.G. If the gauge is widened on the curve, the clearance of check rails is increased by an amount equal to half such widening. The head of the check rail is usually kept level with that of the running rail. The rail, used as a check rail, is a worn rail of the same section or a lighter section than the running rail. Sometimes, the check rail is laid on its side so that the wheel flange comes in contact with the top surface of its head. The practice of providing raised check rails outside the outer rail on curves, so that the outer wheel face comes in contact with it before its flange starts rubbing the running rail, no longer exists. The practice in some countries of spiking the check rail separately, and not bolting it to the running rail, and providing rail braces is also not favoured.

(3) *Guard rails* are provided on bridges of long spans with open floors in order to prevent derailed wheels from falling off the bridge. Guard rails usually consist of old rails fixed about 10″ from each running rail and in the inter-rail space. The top of the guard rails is kept at the same level as the head of the running rail. The guard rails may also be kept slightly lower, but not more than an inch below the running rail. They are joined together with fishplates and the two guard rails converge at points about 50′ to 100′ beyond each end of the bridge. The ends are also bent down at the converging points to prevent hanging or dragging equipment of vehicles from fouling them.

Rails or timbers are also fixed outside the inter-rail space and parallel to the running rails. Their function

is to maintain the sleepers at correct distances and prevent the sleepers from moving when pushed by the derailed wheels They are kept at such distances from the running rails that the derailed wheels are guided not by the outer guard rails but by the inner guard rails, as a derailed wheel, fouling an outer guard rail, is liable to lead to serious consequences Outer guard rails are flared at the ends for the same reason that the inner guard rails are made to converge at the ends

(*4*) *Guard rails* on level crossings have again a different function to those on curves or on bridges These guard rails are fitted to keep the way for the wheel flanges clear, as the space between the rails has to be filled up for making the road surface The guard rails may consist of old rails of any section with one side of the foot planed to give the required clearance of 2 width They may also consist of angle irons or lengths of other suitable sections Formerly, wooden sleepers were required for fixing the guard rails and in tracks having steel or cast iron sleepers the practice was to fix wooden sleepers at level crossings To avoid introducing lengths of wooden sleepers at level crossings steel flats 4 × 1 are used and held 2″ away from the running rail with special cast iron blocks The flat is bolted to the rail through the block and has a ½ bearing on the block In some cases of key type steel and C S T 9 sleepers, a much smaller section of rail is used as a guard rail in place of the steel flat The small section rail does not come in the way of the fittings of these particular sleepers and is bolted to the running rail

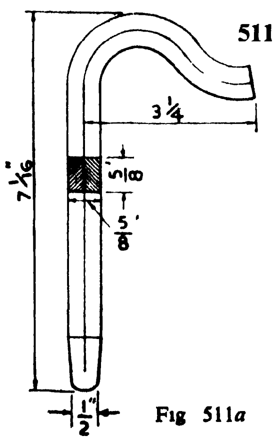


Fig 511*a*

511. Flexible rail fastenings

The wave motion of the rails under traffic has a tendency to raise dogspikes and similar fittings slightly above the rails, thus reducing the pressure on the rail foot This enables creep to take place easily

Elastic spikes (Fig 511*a*) have been in use for some time to overcome this difficulty The special shaped head absorbs the movement due to wave motion of the rail and results in the spike shank maintaining its hold on the

sleeper. A number of proprietary spikes with slight differences in the head are available.

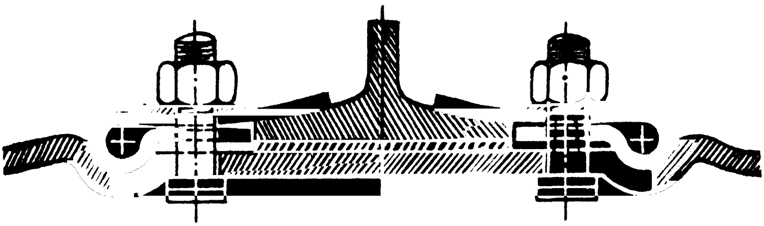


Fig. 511*b*

The *R. N. flexible rail clip* (Fig. 511*b*) is used on the French National Railways with concrete, steel or wooden sleepers. It consists of a heat-treated manganese-chrome spring steel blade, drop-forged to form two leaves and a rounded spring portion. The upper blade is pressed down on the rail foot whilst the lower blade acts as a stop to lateral movements of rails. In some cases, the lower blade is omitted. Such clips are claimed to have given very satisfactory results with long welded rails, particularly in preventing creep. Another flexible rail fastening is the *Hey-Back* soleplate fastening. The soleplate is similar to a bearing plate but has four projecting ribs, the inner twó ribs being slightly curved. The soleplate is attached to the sleeper by bolts and nuts, coach screws, etc. the rail foot occupies the space between the two inner curved ribs and the two outer spaces are occupied by special spring clips. The spring clip is *n*-shaped and the constant pressure exerted by it prevents any movement between rail and sleeper.

Yet another flexible rail fastening is the *Mills* rail clip and base plate. The base plate which is of cast iron is held to the sleeper by screw spikes and has recesses in which one lip of U-shaped spring clips with their lips fairly close is driven. The other lip holds the foot of the rail.

Various methods are adopted for fixing the rail fastening to the concrete sleeper. The two most common are (*1*) Tee bolt fitting used with the French composite type sleeper and (*2*) corrugated hard-wood plug used on German Railways (Figs. 512*b* and 512*c*). The Tee bolt head is engaged in the portion of the tie bar projecting in the concrete block. It is possible to replace corrugated plugs by drilling them out, and replacing with split plugs which after insertion in the hole in two pieces are tightened by driving home a wedge between the two halves. Two other methods of attaching rail fixtures to concrete sleepers are shown in Figs. 512*d* and 512*e*.

Yet another method is to cast in the concrete a soft aluminium or plastic helix and to subsequently thread screw spikes through them Nylon inserts are also being used

512. Rail fastenings for concrete sleepers

As already indicated in para 311, a resilient fixture between the rail and the concrete sleeper is required if deterioration of the concrete through pounding is to be avoided Moreover, as concrete sleepers are very suitable for use with long welded rails, the fixtures should have adequate grip on the rail to contain the locked up temperature stresses and prevent creep Yet another requirement is that as welded rails have sometimes to be freed for stress-relieving purposes (*vide* para 1504) the fixture should provide a ready means of freeing and retightening rails without subsequent diminution of the grip

Fig 512*a*

A resilient soleplate (*vide* para 513) is provided to sustain the impact

All the flexible fastenings mentioned in para 511 can be used with concrete sleepers but the spring spike falls short of the requirement for stress relieving The R N clip is extensively used with composite concrete sleepers in France It belongs to what may be termed the elastic as distinct from the "rigid" group of fastenings

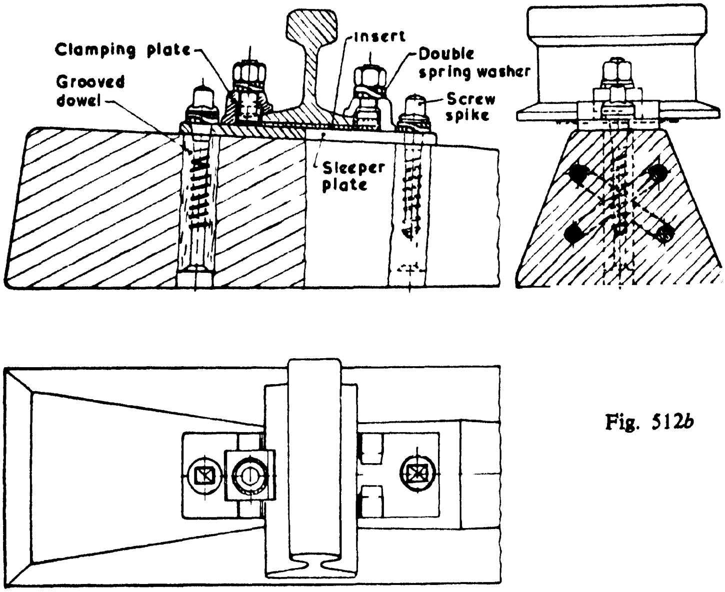


Fig. 512b

with concrete sleepers. The British Railways have also developed leaf spring clip fixed to a wooden plug cast in the concrete sleeper. The fixing is done by means of a screw spike with a threaded

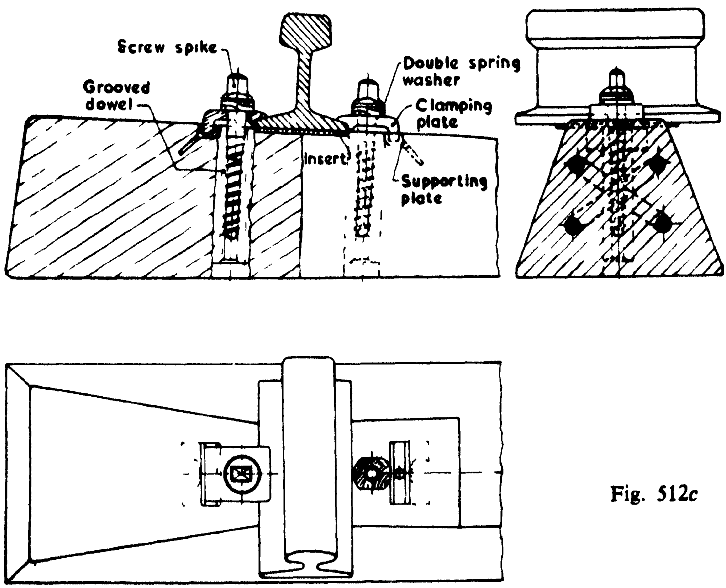


Fig. 512c

alternative fastening. One consists of a rolled or forged double top in which the clip is inserted and tightened with a nut. In the alternative fastening, the double leaf spring clip is supported by a shaped plate which is used for holding the rail foot to correct gauge (Fig. 512*a*).

The "rigid" type of fastening is used extensively in Germany and the heavy and light types are illustrated in Figs. 512*b* and 512*c* respectively. The heavy type has a base plate attached with screw spikes to the sleeper through plugs. The base plate has lugs which hold "hook" bolts by which shaped clamps engaging the rail foot are held. Spring washers provide the flexibility. In

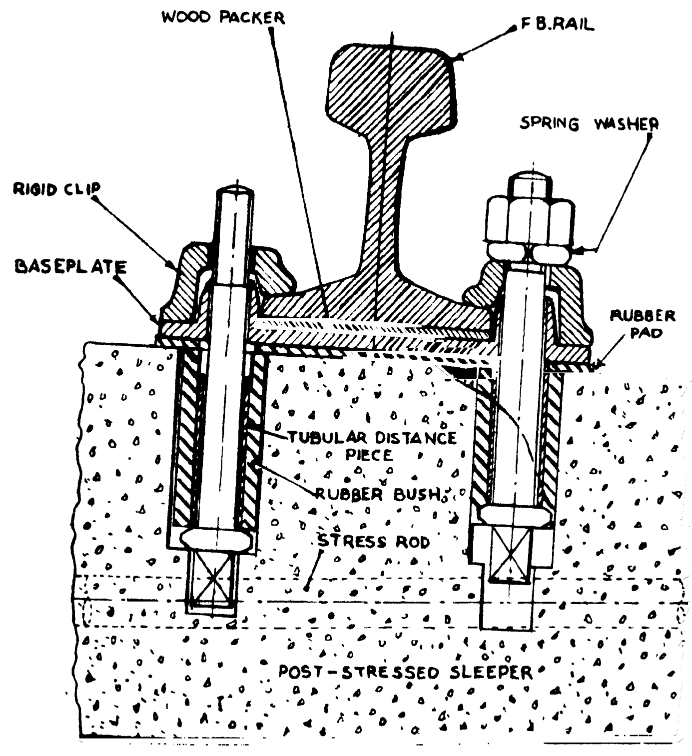


Fig. 512*d*

the lighter type, the base plate is omitted and the clip arrangement is simpler.

The English and Austrian versions of the "rigid" fixtures are shown in Figs. 512*d* and 512*e*. Base plates are provided in both cases. The lateral movement of the rail is prevented by the projections on the base plate.

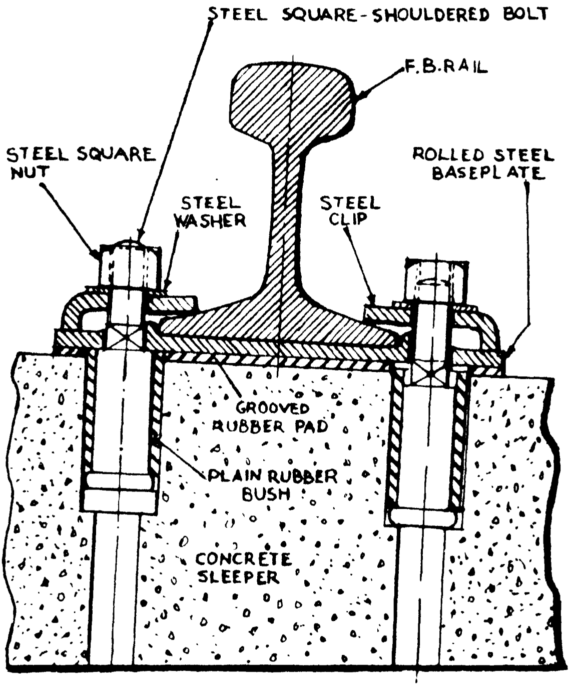


Fig. 512*e*

The grip between the rail and the base plate is firm, the clips being rigid and made of non-spring steel. When the nuts are tightened the shoulders of the special shaped bolt or the tubular distance piece engages with the bottom surface of the base plate and holds the rail firmly. This arrangement also has considerable hold against longitudinal movement of the rail. The base plates rest on rubber pads and the round bolt shanks are surrounded by rubber sleeves. When the nut is tightened the rubber sleeve is compressed against the wall of the hole in the concrete sleeper and provide a firm resilient grip. The bolt is prevented from turning with the nut by a square portion the bolt shank engaging in a square hole in the base plate in the British type. In the Austrian type the square shank is housed in a square slot in the concrete sleeper.

513. Resilient soleplates

As indicated in para 311, a resilient pad or soleplate is required with concrete sleepers to prevent deterioration of the sleeper through pounding or impact. As both the soleplate as well as the rail fastening (*vide* para 512) have to be elastic, a relationship with regard to the elastic strength of each needs to be established.

The rail deflects downward and upward in the form of a series of waves with the passage of wheel loads and the rail fixture together with the elastic soleplate has to hold the rail with sufficient pressure during both its downward and upward deflection.

When a predetermined pressure is applied to the fastening for holding the rail, an equivalent compression is introduced in the elastic soleplate. When a wheel load passes over the rail just above the soleplate a further compression occurs in it. This additional compression reduces the grip pressure in the fastening by an equal amount.

When the rail deflects upward, due to wave action, immediately after the passage of a wheel, it increases the pressure on the fastening. This results in the compression in the soleplate being reduced by an equal amount.

It will be appreciated that in the first case, if the compression in the soleplate is large enough, the fastening may loose its grip on the rail completely with the possibilities of longitudinal movement or creep of the rail, particularly with long welded rails.

Similarly if the upward movement of the fastening is large enough, the compression on the soleplate may be totally eliminated with the same results.

Satisfactory conditions may be established if the compression of the soleplate is reduced under the downward load and the stiffness of the fastening is increased under the upward load. In other words, both equipments should have a two-stage stiffness, that under the initial tightening of the fastening being less than when the loads are applied.

In the case of the soleplate, this is made possible by having a chequered design on one surface, as this has lesser compressive stiffness. When loads are applied, the solid portion of the soleplate provides the increased stiffness.

In addition to the two-stage stiffness requirements, provision has to be made in the soleplate to allow for the load distribution across the rail not being uniform but parabolic and also for load

concentration at the edges of the sleeper due to the wave action of the rail.

Of the various materials such as wood, felt, cord, rubber, both natural and synthetic, and rubber-bonded cork, tried out for soleplates, synthetic rubber has been found to give the most satisfactory results, provided design requirements, as outlined above, are fulfilled. Plastics of suitable quality are also likely to provide alternative satisfactory materials for soleplates.

Ballast and Formation

601. Function of ballast

BALLAST in railway tracks is used in the form of a layer of broken stone, or other suitable material, under and around the sleepers, for distributing the load from the sleepers to the formation. It provides a suitable foundation for the sleepers and also holds the sleepers in their correct position preventing their displacement by longitudinal or lateral thrusts. The lateral stability of a track depends on the ballast. It provides an easy means of correcting track levels and increases the elasticity of the track. For optimum results with respect to the elasticity of the track, the ballast should be free of dirt and should be well consolidated. It helps in protecting the top surface of the formation. The track is also drained through the ballast and for this reason, a permeable layer of ballast is preferred. Ballast is also easily handled. Ballast for a railway track should be coarse and rough.

The load which a track can support without being unduly depressed depends on several factors, including the strength of the rail, type, size and spacing of sleepers, stability of formation and on the quality, condition, and depth of ballast.

602. Types of ballast

Materials used as ballast are broken stone, gravel, sand, ashes, "moorum," "kanker," overburnt and broken brickbats, blast furnace slag, and sometimes selected earth. The best material is *broken stone* and almost all important tracks are provided with stone ballast. The best stone for ballast is a non-porous, hard, angular stone which does not flake when broken. Igneous rock such as hard trap, also quartzite and granite, make excellent ballast and are used in large quantities in India. Where such hard stone is not available, sandstone and limestone, which are softer, but which also make fairly good ballast, are used.

Gravel ranks next in its suitability for use as ballast and is used in large quantities in many countries. Gravel or *shingle* may be obtained from river beds or may be dug out of gravel pits. It is not as good as broken stone as the smooth stones roll down easily due to vibration and the packing under the sleepers gets loose. Shingle, as obtained from gravel pits, is full of earth and it has to be cleaned, if proper drainage of the track is to be obtained. Gravel, particularly that obtained from river beds, varies in size considerably and it is advisable to screen such gravel, break the very large pieces or eliminate these and also remove the extremely small pieces. Gravel is usually cheaper than broken stone as it has not to be broken.

Ashes or cinders, available in large quantities on railways from coal, used in locomotives, has excellent drainage properties as it is very porous. Due to its low cost, it is largely used in sidings. It cannot be used for main lines as it is very soft, gets easily reduced to powder by packing and vibration and makes the track very dusty. It is excellent for yards where it is used as ballast under the track and it forms excellent paths between tracks for shunting staff, particularly in rainy weather as it does not retain water and is not slippery. One great drawback of ashes is its corrosive quality and ash ballast must not be used with steel sleepers, as such sleepers are corroded in a short time. The foot of the rail is also affected by corrosion in ash-ballasted tracks. In an emergency, such as that caused by the destruction of track lengths by floods, it is invaluable, as it can be used equally well for repairing formation or as ballast for packing tracks. It is also invariably available in large quantities at short notice.

Sand forms another reasonably good material for ballast. It is a good material from the point of view of drainage, provided it is free of earth and vegetation; it is also comparatively cheap. Sand ballast produces a silent track and has been found to be

particularly good for packing pot sleepers As sand can be easily blown or washed away, such ballast has to be constantly recouped. It is disturbed easily by vibration and the maintenance of a sand ballasted track is therefore difficult. Heavy wear occurs to vehicles moving over a sand ballasted track, as the sand gets into the moving parts and causes friction. Sand ballast is sometimes covered with a layer of stone to prevent it blowing about too much. Coarse sand is to be used in preference to fine sand, and the best sand for ballast is that which contains a quantity of fine gravel varying in size from $\frac{1}{8}''$ upwards. Sand is often used on narrow gauge tracks. A covering of sand ballast is sometimes given on tracks in yards with good results, as it soaks up water, makes easier walking for the men working in the yard, and as the surface can be swept, the yard is kept clean.

Moorum is found in many parts of India. It is the result of decomposition of laterite and has a red and sometimes a yellow colour. All moorum is not good for use as ballast. Moorum hich is soft and very sticky is worse than useless and moorum suitable for ballast has to be differentiated from red earth. The best moorum for ballast is that which contains large quantities of small laterite stone. As laterite is soft, it turns to dust in a short time and moorum cannot be recommended for use except in sidings. For sidings and for main tracks, when they are newly laid and the embankments are not sufficiently consolidated, moorum is a good material to use. When stone ballast is eventually put in the track, the moorum forms a soling or blanket under the stone ballast.

Kanker, which is a lime agglomerate, is found in many places in the form of nodules of varying sizes. It is common in certain clay soils and is dug out of the ground. Where stone is not easily available, it is used as road metal and as ballast for railway tracks. It is however soft and even the harder variety, used as ballast, powders easily. It is useful for metre and narrow gauge tracks with light traffic and where a better type of ballast is not available.

Brick ballast.—Where no stone or substitute is available for use as ballast, overburnt bricks are broken into small sizes and used. It powders easily and produces a dusty track. Rails in tracks laid on brick ballast are often found to be corrugated. Brick ballast however is fairly good for drainage.

Blast furnace slag, which is a by-product in the manufacture of iron, forms a suitable ballast material. It should however be hard, of high density and free from gas holes. Slag suitable for use as ballast is obtained by pouring molten slag collected at the blast

furnace into shallow pits in thin layers, allowing it to cool, then digging, crushing and screening. The object of pouring the molten material in thin layers is for rapid cooling to ensure a satisfactory material and for preventing gases being trapped resulting in holes.

Selected earth.—For sidings, earth, if of suitable quality, is sometimes used as ballast. It is also sometimes used on new formation as a temporary measure. Indurated clay and decomposed rock are suitable materials.

603. Size of ballast and section of ballast layer

The size of the ballast used varies from $\frac{3}{4}''$ to $2\frac{1}{2}''$. Stones of larger sizes are not desirable and 2″ as the maximum size is preferable as interlocking of stones of this size is better than of stones of larger size. In some countries the maximum size is given as 3″. The best ballast is that which contains stones varying in size from $\frac{3}{4}''$ to 2″ with reasonable proportion of intermediate sizes. Smaller ballast is used in some countries as a top layer for finer adjustments in the level of the track. Where *shovel packing* is in vogue ballast of size $\frac{1}{4}''$ to $\frac{1}{2}''$ and even less is necessary. In shovel packing, the track is raised and small quantities of ballast spread with special shovels on the packed ballast under the sleepers.

The depth of ballast under the sleepers is an important factor in the load-bearing capacity of the track. Experiments in America have shown that the load-bearing capacity of a track, with 9″ depth of ballast under the sleepers, is 30% greater than that of a track with 6″ ballast. It is not good practice, therefore, to starve a track of ballast, provided the ballast is not wasted in making the ballast layer wider instead of deeper or in keeping it above the level of the top of the sleepers. A depth of ballast equivalent to the sleeper spacing has been recommended in America. This would give an unnecessarily thick layer of ballast in India, where the sleepers may be as much as 36″ apart, but is suitable for the much heavier loads and the closer spacing of sleepers existing in that country. The width of the ballast layer is also important, as the lateral strength of track depends partly on the quantity of ballast at the ends of sleepers. The lateral strength increases with increase in width of the ballast layer but there is a limit beyond which no useful purpose is served by widening. The limit is variously computed at 15″ to 17″ from the end of the sleeper. Formerly ballast was heaped almost upto rail level on the shoulders, namely, the portions outside the inter-rail space. The ballast above sleeper level serves no useful purpose and ballast is now spread level with the top of the sleepers. American practice

is to keep the ballast flush with the top of the sleeper at the centre of the track and to slope it down towards the shoulders at a slope

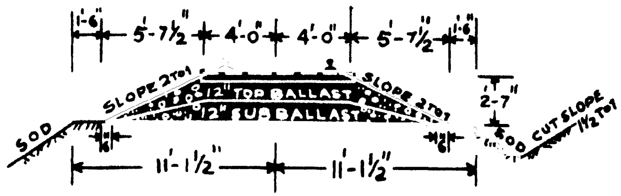


Fig. 603*a*

of 1 in 24 (Fig. 603*a*). The shoulders are rounded from near the end of the sleeper and then sloped to the formation at 2 to 1. The depth of the ballast is 12″ to which an additional 12″ of *sub-ballast* or *soling*, made of larger stones, is given. The 12″ depth is for the class A or important tracks, and is reduced to 9″ for Class B and 6″ for class C tracks. In India, the distance from shoulder to shoulder is 11′-0″ for B.G., 7′-6″ for M.G., and 6′-0″ for N.G. The minimum depth of ballast required below sleepers is 8″ for B.G. and 6″ for M. G. and N.G. (Fig. 603*b*). Slopes of 1½ to 1 or

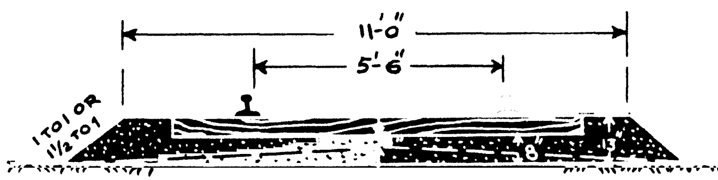


Fig. 603*b*

1 to 1 are used at shoulders and although, perhaps, these slopes are not as easy to maintain as 2 to 1 slopes, a poorly maintained portion of track can be spotted easily, as the stones roll out beyond the toe of the ballast due to vibration. Neat shoulders of ballast are, however, not infallible signs of good maintenance.

604. Quantity of ballast

With the above section, approximately 12 c.ft. of ballast is required for every foot length of B.G. track and 8¼ c.ft. per foot length of M.G. track. Slight variations in quantities occur with the type of sleeper used. Wooden and concrete through sleepers,

because of their bulk, require slightly less ballast than pot or trough sleepers. The quantity of ballast required on curves is a little more than on straights due to the sleepers having to be laid at a slight slope for producing the required superelevation in the outer rail. The minimum depth of 8″ should be kept below the rail seat of the inner or lower rail on a curve. It is also advisable to have a wider shoulder on the outside of the curve to counteract the greatly increased lateral thrust, and help to prevent any displacement.

With sand, ashes, moorum or earth, the ballast profile should be as shown in Fig. 604*a*.

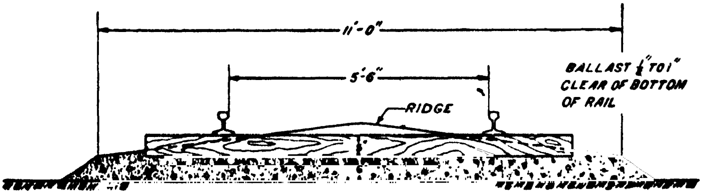


Fig. 604*a*

The ridge at the centre and clearances of about ½″ to 1″ below the rails allow rain water to drain away freely, even when the ballast is impervious, as is the case with moorum, earth, dirty sand and dirty ashes. If this slope is not given, the track gets sodden and it is very difficult to keep it in good condition in the rainy season.

Some track inspectors are found to be averse to this section, on the ground that as the ballast is not heaped up at the ends upto the level of the sleepers, the lateral stability of the track is affected. The author can assure them that this is not so serious a consideration as it would appear, as the sleeper end has still a depth of 3″ to 4″ buried in ballast and he has not found any displacement of tracks carrying heavy traffic and on which this section was adopted in moorum ballast.

A stone ballast profile having a shallow central depression or drain (Fig. 604*b*) is also used. The central depression prevents

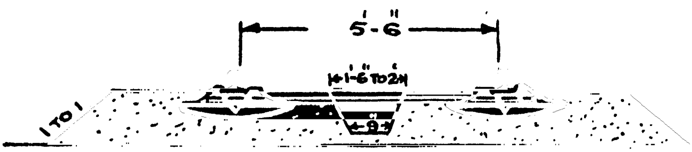


Fig. 604*b*

centre binding of sleepers (*vide* para 1106*g*) and this is an advantage with steel trough and concrete sleepers. It has a drawback, in that ballast from under the rail seats is liable to roll into this depression due to vibration, but if the depression is kept small, it is sufficiently far away from the rail seats to cause any loosening under the rail seats. Cross drains, about one in every three rail lengths, are desirable with such a section. The central depression or drain, with cross drains at short intervals, is a desirable feature on new tracks and on tracks with formation of very poor soil.

605. Supply and renewal of ballast

The quantity of ballast is constantly decreased by crushing and powdering and by being pressed down into the formation. Fresh ballast has therefore to be added periodically so that the layer of ballast retains the correct depth and width. Ballast is collected in long narrow windrows or stacks along the track if suitable stone is within easy reach. This is done when a new railway line is built, but in many cases on construction and invariably for renewing ballast on an existing track, the material is unloaded, where required, from wagons. The ballast is loaded at a stone quarry, or a ballast depot, into wagons, which may be open on top and have low sides with suitable doors or which may be of the hopper type. Ballast is unloaded by gravity from hopper wagons either in the inter-track space or outside the rails. If ballast has to be unloaded from other types of wagons, it has to be shovelled out. A number of ballast wagons are formed into a special train and moved over the track to be ballasted at a very slow speed for unloading the ballast.

The quantities to be unloaded are worked out beforehand and the lengths on which the ballast is to be unloaded are suitably indicated, twigs and branches being commonly employed for the purpose. As each wagon carries a fixed quantity, the usual way to ensure that the correct quantity is unloaded is to specify that ballast from each wagon should cover a specified number of rail lengths. Some maintenance men do not give this item the attention it deserves and unloading is often done by mere judgment. The result is that unnecessarily large quantities are unloaded in some places and insufficient quantities in other places. The quality of ballast required is also often considered a matter of judgment. This again is not very satisfactory and a simple method of determining a reasonably accurate quantity is to measure the existing ballast section at fixed distances, say every $\frac{1}{4}$ or $\frac{1}{2}$ mile, arrive at the quantity required by deducting the existing section

from the normal section and unload the quantity thus computed over the length on which each sample measurement is taken. When *make-up ballast* is required during screening, a rail length is screened every ¼ or ½ mile and the quantities worked out as above.

After the ballast is unloaded it has to be *boxed*, namely, heaped to correct section. This work must follow immediately behind the unloading. Special devices for unloading, apart from hopper wagons, and for spreading ballast are not used in India but are common in America. A mechanical plough for unloading ballast from flat wagons, whose sides and ends can be opened out, is of the same width as the wagons and is pulled by a wire rope worked from one end by a winch. The plough is guided through the wagons by posts on the sides of the wagons. The device for spreading ballast, unloaded on the track, may be as simple as a set of sleepers at rail level attached to the end of a wagon and dragged over the rails.

Stone ballast is obtained from boulders or from solid rock by removing large pieces of the rock by blasting. Explosives used for blasting are gunpowder, dynamite, gelignite, etc. The large pieces are broken into rubble and the rubble is crushed in a ballast crusher or broken into small ballast by hand. The manual process is laborious but is often employed. Mechanical crushers produce suitable graded ballast. The commonest type of crusher, namely, the jaw crusher, consists essentially of two jaws, one fixed and the other movable. The fixed jaw with its sides, together with the movable jaw form a hopper into which rubble is dropped. The movable jaw is vibrated by means of a cam turned by an engine, and the rubble is crushed between the jaws.

Another type is the gyratory crusher which consists of a vertical lined cylinder with a conical rotating piece. The conical piece rotates eccentrically and crushes the stone between the cylinder and the cone walls.

The ballast after crushing is screened. Screening may be done manually by throwing ballast against a frame with the requisite size mesh held at an angle on the ground. Mechanical screening is done either by rotary screens or flat vibrating screens.

Ballast is usually stacked for purposes of measurements. As the ballast is full of voids, it settles a little with time and on some railways a deduction is made for such settlement, the usual amount being 1″ per foot of height or approximately 8%. Ballast loaded in wagons also settles due to vibration of the moving wagon; the amount of settlement depends on the shape, size and grading of stone.

Specifications for stone ballast generally prescribe the percentages of smaller material permitted. The size of ballast is tested with rings of diameters equal to the largest permissible size of the ballast.

606. Stabilising track on poor soil

In Britain and America, a layer of sub-ballast made of stone, larger than the ordinary ballast and varying in depth from 6" to 12" is usually provided. No such sub-ballast is put in the track in India, but where trouble is experienced with poor quality of soil, a layer or blanket of moorum or ashes is laid under the ballast, with good results. Black cotton soil which is a fine black loamy soil, has the property of expanding when moist and of caking and cracking heavily when dry. Tracks laid on formation made of this or similar soil are difficult to maintain. In the rainy season, the track heaves up in places, the soil fills the ballast interstices, the track in the worst places gets sodden and spongy and the lateral stability of the track is reduced. In the hot weather, ballast is lost in the cracks, affecting the alignment and level, and due to mud having filled the interstices, the track loses its resiliency. A 12" layer of moorum or other suitable material, laid between the formation and ballast, goes a long way to overcome this difficulty. A layer of any material which distributes the pressure and prevents ballast from being lost in the cracks is suitable. A layer of unserviceable sleepers has been tried and slabs of concrete have also been introduced with success. Of the above methods, the moorum or ash blanket is the cheapest and is quite effective.

An effective and economical method of stabilising formation known as *sand piling* has been introduced in America. The process consists of driving in the formation a 12" timber pile to a depth of approximately 6 feet, withdrawing the pile and filling the hole with sand. By this method about 20 per cent. of the top section of the formation is replaced with sand. Piles are sited (*1*) at the two ends of each sleeper, (*2*) outside the rails and between sleeper ends, and (*3*) in the inter-rail space at the rate of two piles and one pile in alternate sleeper spaces. The driving of the piles is staggered to avoid closing of adjacent holes before sand filling whilst the adjacent pile is driven. During sand piling operations, the track heaves up by about 3".

Another method of stabilising formation is to inject cement *grout* under pressure. Injection points which consist of double strength $1\frac{1}{4}$" diameter pipes are driven into the formation at every second sleeper spacing. The point of application is near the end of the sleeper and the injection points which are about 5' long are

driven at an angle so that the point is under the rail. Grout is forced under a pressure of 100 p.s.i., the composition of the grout varying with the type and condition of formation. At first water is forced through the injection points, followed by a mixture of one bag of cement per 10 gallons of water. Unless the flow is obstructed, thicker grout with an admixture of fine sand (passing No. 14 B.S. sieve) in various proportions commencing with 25 pounds of sand per bag of cement are tried. The grout successfully consolidates poor formation.

607. Formation and drainage

The stability of a track depends on the quality of the formation under it. The formation which consists of a series of embankments and cuttings has to stand up to all the loads coming on the track. The formation must be of suitable width and must have stable slopes. The width of the formation depends on the number of tracks which are to be laid on it, the gauge of such tracks, the width of the ballast layer, and widths of drains on either side, if the track is in a cutting.

For B.G. tracks, a width of 20′ on the banks and 18′ in cuttings is recommended for a single track. In cuttings 4′ are to be added for the two side drains. The corresponding figures for M.G. are 16′ and 14′ and for N.G., 12′ and 11′. Slopes of 2 to 1 are given on banks, whilst those of cuttings are 1½ to 1 or steeper. The sides are made vertical where solid hard rock exists.

The usual manual method of constructing banks in India is to dig pits called *borrowpits*, in the adjoining ground. In other countries, earth is carried from cuttings, or elsewhere to form the bank. As loose earth gradually sinks when it consolidates, a sinkage allowance of approximately 2″ per every foot of height is added on top. To prevent erosion of loose soil in rain, the slopes are turfed.

Earth moving machinery is being increasingly employed in India for the construction of banks and cuttings and the earth excavated from cuttings is used for building up embankments where feasible. The machines most extensively used are *scrapers* and *bull-dozers*. The scraper (Fig. 607*a*), as its name implies, slices off layers of earth which is automatically filled in a container forming part of the machine. The load is carried to the place where it is to be deposited and the container is opened at the bottom through suitable mechanism and earth is deposited in a uniform layer. As the scraper travels over deposited earth, it automatically consolidates it. The bull-dozer, which has a powerful blade is

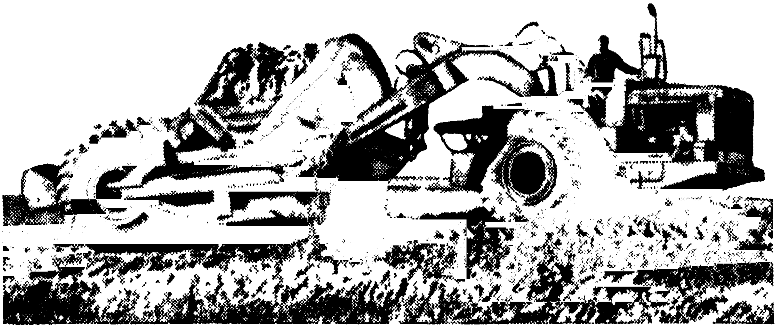


Fig 607*a*

used for breaking up hard ground to enable the scraper to scoop up the loosened material. The bull-dozer is also used for transferring earth by pushing with the blade when the distance over which the earth is to be covered is not great. It is also used for many other purposes such as levelling the ground, removing brushwood and even small trees, assisting the scraper by pushing it when necessary, and pushing heavy materials including boulders.

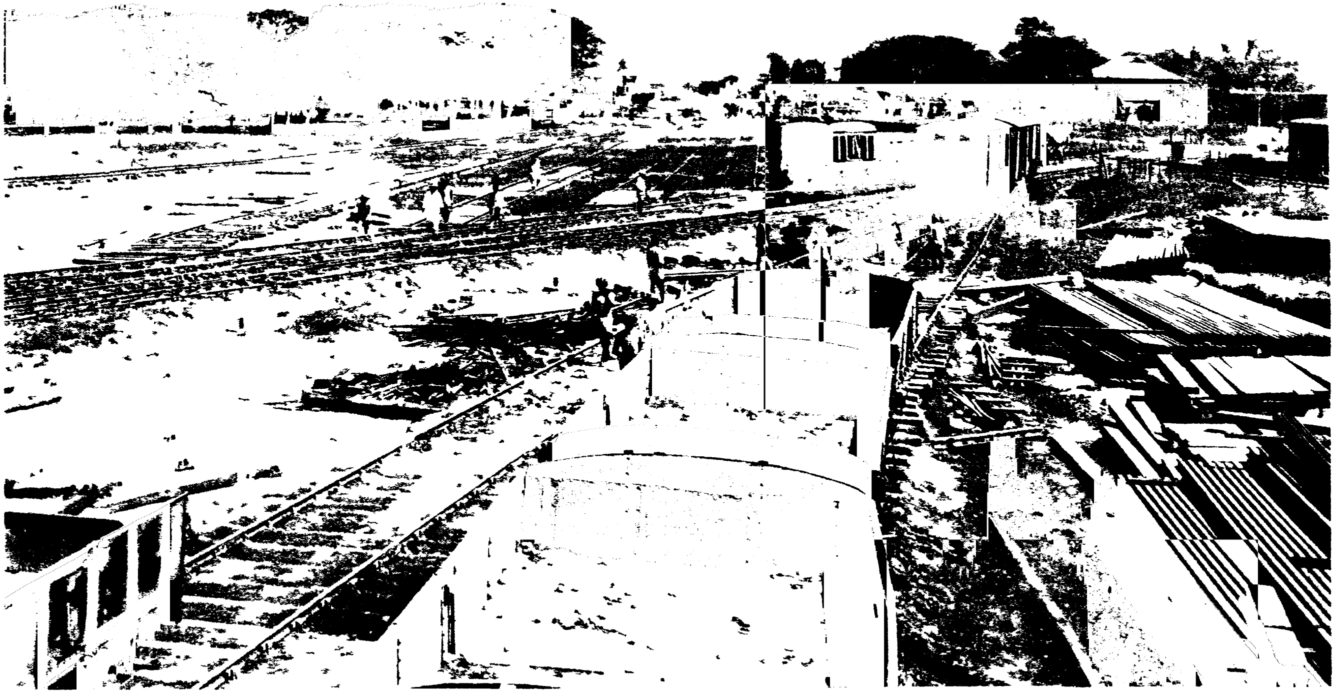
To make up loss of earth due to erosion and sinkage, earth has periodically to be added to banks. This addition is invariably made along the shoulders and the earth is obtained from shallow pits a little distance from the toes of the banks. A diagonal ridge known as a *witness* is left in square or rectangular pits for measurement purposes and these are removed after measurements are taken.

When such repairs are carried out, lumps of earth should be broken after being deposited on the bank and the surface should be dressed. Sufficient land is retained on either side of the track in which pits may be dug.

The ballast, provided it is properly maintained, drains the track of rain water. When the water reaches the surface of the formation below the ballast, it drains out on the sides provided the formation presents an impermeable surface. Unless the formation soil is poor (e.g. black cotton soil) no special provision is required in banks but special provision has to be made for water in the cuttings. Drains about 2′ wide and 1′ deep are cut on either side of the track and a few inches from the toes of the ballast layer. In long cuttings, the volume of water increases at the lower end and drains have to be made wider at this end than at the upper end. Pitching on the side of drains nearest the track is also sometimes necessary, whilst in some locations, a fully pitched or built up drain is essential.

PART 2

Layout and Construction



A railway yard under construction

Points and Crossings: Description and Design

701. Description of points and crossings

POINTS and crossings supply the means by which a train may be transferred from one track to any other track, either parallel to, or diverging from the first track. A set of points and crossings (Fig. 701) consist of two main parts, the *Points* and the *Crossing*. *Stock rail* NB and *tongue rail* HJ form a *switch*. Similarly, PD and KF form another switch. The two switches form a set of *points* which divert the train. The tongue rails are planed to very thin sections at the *toes of switch* F and H to obtain a snug fit with the stock rails. The tongues may be straight or curved. In India,

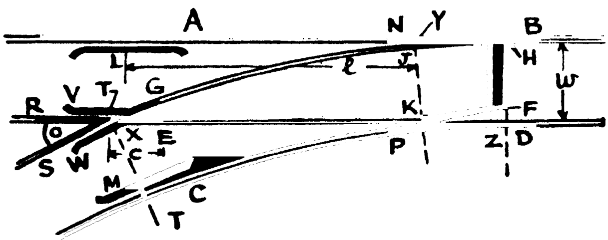


Fig. 701

Straight tongue rails are generally used, whilst in Britain, curved tongue rails are favoured. The tongue is connected to the stock rail at the *heel of the tongue* with the help of a *heel block* and ordinary fishplates. The tongue rails are supported on *sliding plates* and each pair of tongue rails is connected together at the toe with *stretcher*

bars FH, so that both tongues move through the same distance or gap FD.

The *crossing* GERS enables the flanges of wheels to cross the rails. The points are connected to the crossing with ordinary rails, either laid straight as at EK or on a curve as at GJ, and are known as *lead rails*. *Check rails* are provided at L and M for guiding the flange of a wheel, whilst the opposite wheel on the same axle is negotiating the gap X at the crossing. The wheel is liable to move sideways at this gap, unless guided by the opposite wheel, and this is possible, as the wheels are rigidly fixed to the axle. T is the *nose of the crossing*, RS the *heel of crossing* and RT and ST are *point* and *splice rails* respectively. Both these rails are planed and connected together rigidly, the point rail ending at the nose and the splice rail a little behind the nose. VG and WE are *wing-rails* and the narrowest space between the two wing rails, where they are bent, is known as the *throat*. The angle made by the lines RT and ST, namely, the gauge faces with which wheel flanges come in contact, is known as the *crossing angle*. The size of the crossing is measured by this angle, as explained later. The point, splice and wing rails are all built up into one unit with bolts and rivets. Formerly crossings were cast in one piece. The present practice is to build them up from standard rails either of ordinary carbon steel or of alloy steel, such as manganese steel. The points are moved through *point rod* Z by a *point lever*. *A self-reversing lever* enables the points to be moved in either direction by turning the handle in the same direction, from a fixed position. It also holds the tongue rail under pressure, so that the possibilities of a gap between the stock and tongue rails are avoided. The point lever may be close to the points or situated in a distant cabin and connected to the points with *rodding*. The points are also often worked electrically or pneumatically. In Fig. 701, the points are set for a train to travel over the curved or branch track. If the train is moving from F towards C, the flange of the left wheel enters the gap FD, whilst the flange of the right wheel is diverted towards the curved track by the tongue HJ. The right flange subsequently passes through the throat and is then guided by the wing rail WE. The left wheel flange is guided by the check rail M and this keeps the right wheel in its path whilst negotiating the gap between the throat and the nose of the crossing. The check rail is extended well in front of the nose of the crossing, so that one wheel is steadied by the check rail and the opposite wheel is prevented from striking the nose of crossing. If a train travels from the toe towards the heel of the switch, the points are known as *facing points*. If the movement is in the opposite direction, the points are called *trailing points*. The same set of points can act as facing as well as trailing points. If a train is diverted to

the left by the points, as is the case in Fig. 701, the assembly is known as a *left hand turnout*. Similarly a *right hand turnout* diverts a train to the right. When standing facing the points, HJNB on the right, is the *right hand switch* and FKPD is the *left hand switch*. The distance between the heel of switch K and the *theoretical nose of crossing*, just ahead of the actual nose T, is called the *lead*. There is a slight difference between the theoretical and actual nose of crossing, as the theoretical nose is a point connecting the gauge lines of the point and splice rails whilst the actual nose has to be set back a little, to permit a little thickness at the nose. The curve, between the heel J of switch and the toe G of crossing, is the *lead curve* and the distance from the end D of the stock rail to heel R of the crossing, is the *overall length*.

702. Description of various layouts

Various combinations made of points and crossings, with curves and straights, to transfer trains from one track to another or to enable trains to cross other tracks are described in this para.

(*1*) In some of the combinations, a type of crossing is used, known as an *obtuse crossing* as distinct from the *acute or Vee crossing* described in para 701. In Fig. 811, A and B are acute crossings and C and D are obtuse crossings. Obtuse crossings are necessary together with acute crossings where one track crosses another. The point D is the *elbow*, J is a check rail and there are two noses, at GG, in an obtuse crossing. The gap at the elbow of an obtuse crossing is longer than the gap between the throat and nose of a Vee-crossing.

(*2*) The simplest combination of points and crossings is a *turnout* (Figs. 804 [without the portion GNA and the track to the right of it shown in broken lines], 807 and 808) which enables one track, either a branch line or a siding, to take off another track. (Figure 804 as illustrated is a crossover explained in para 702 (*4*)). The branch or siding may run parallel to the main track, as in Fig. 804, or may diverge from it, as in Figs. 807 and 808. In case of turnouts to parallel tracks, a straight CK is laid behind the crossing, before the *turnout curve* PC is introduced. If space for the siding is restricted, the straight CK is left out and a *reverse curve* is introduced. The radius of curve PC is usually kept the same as the radius of the lead curve DH. Turnouts may also be taken off the outside, or the inside, of curved tracks to parallel curved tracks, but such turnouts should be avoided, due to difficulties in providing superelevation (*vide* para 1309) and in introducing a suitable turnout curve.

(*3*) If the radius of the main track curve is equal to that of the turnout curve, the turnout is a *symmetrical split* (Fig. 803) since the turnout is symmetrical about the centre line. A symmetrical split may be used also on a straight track and, in this case, the centre line of the main track beyond the symmetrical split is moved bodily by half the spacing between the two tracks.

In case of turnouts from inside of curves, if the main curve is flat, the turnout and the siding curve forms a reverse curve (*vide* Fig. 702*a*). If the radius of the main curve is less than that of the lead curve, the turnout curve will be of the same flexure as the siding curve, but this turnout curve will become very sharp (*vide* Fig. 702*b*).

With regard to turnouts from a straight track to a diverging track, the radius of the turnout curve is made the same as that of the lead curve. If the diverging track is to take off the inside, or the outside, of a curved track, the crossing is fixed in a suitable position in the main curved track and the heel of crossing joined to the diverging track with a suitable curve.

(*4*) A *crossover*, as the name implies, is a means of transferring a train from one continuous track to another continuous track;

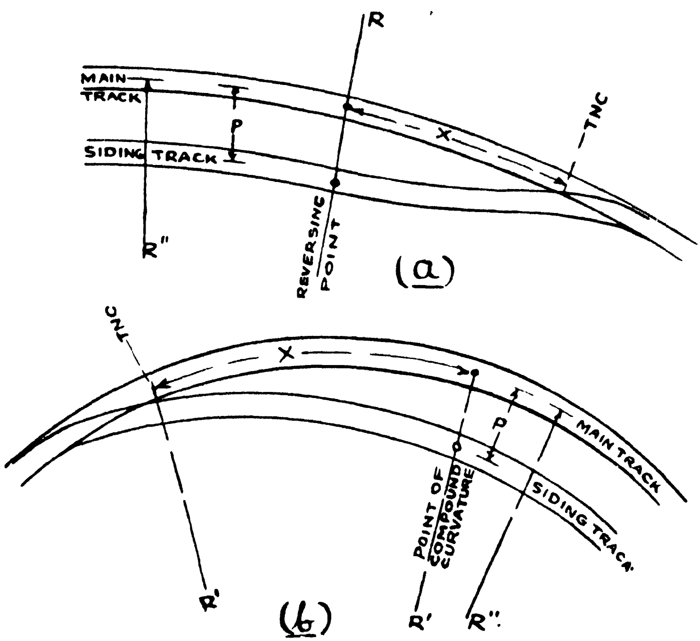


Fig. 702

these tracks may or may not be parrallel to each other. The crossover consists of two sets of points and crossings, with a connecting straight between the heels of the two crossings. Fig. 804 depicts a crossover between two parallel straight tracks. A reverse curve between the two crossings shortens the length of the crossover, but such a layout is only suitable for low speed sidings. The saving in length is also very little with the normal spacing of the tracks; with 1 in 8½ crossings and 15′-6″ spacing of tracks, the saving in length is about 2′-6″. When the tracks, however, are far apart, an appreciable saving occurs in the length of crossover.

A crossover between two parallel curved tracks is similar to that between straight tracks, but the heels of the crossings instead of being connected by a straight track, are joined together with a curve, the radius of which is the same as that of the curved main track. On sharp curves, in order to save space, crossings of different angles are used. The crossings with the large angle is used on the inner curve and that with the smaller angle on the outer curve.

A crossover between diverging tracks is laid in the same way as a crossover for parallel tracks, but an extra length of curve has to be introduced behind the heel of crossing, nearest the junction of the diverging tracks (*vide* Fig. 809). A connecting reverse curve is also sometimes used instead of a straight, in order to save space.

(*5*) When one track crosses another track of the same, or of a different gauge, at an angle, a *diamond crossing*, so called from the shape of the layout, has to be installed. The diamond crossing consists of two acute and two obtuse crosssings (*vide* Fig. 811). If a curved track crosses a straight, or another curved track, a *curved diamond* is required. When the tracks cross at right angles, a *square diamond* is installed. Crossing of tracks at a very sharp angle is undesirable. The other extreme, namely, a square crossing, is equally undesirable. The reason in both cases is that the flange spaces for both wheels come opposite, or almost opposite each other and produce jolts and bumps; there is also a slight possibility of derailment.

(*6*) *Double junctions* are necessary where a branch takes off a multiple track. They are a combination of ordinary turnouts with one or more diamond crossings (*vide* Fig. 813). The simplest arrangement is to introduce a straight behind the turnout and let the straight cross the other tracks. The acute angle of the diamond crossing with this arrangement is the same as the angle of the turnout crossing.

(*7*) If tracks are to be so arranged, that a train normally crosses another track, but when required, it may also be diverted to this second track, the arrangement, shown in Fig. 812, and known as a *diamond crossing with slips*, is installed. ABCD is a diamond crossing. HG and JK are two pairs of switches, one switch of each pair being placed inside the diamond. The switches are connected by suitable curves KH. A train may travel from X to Y, or Y to X, crossing the track WZ. It may also be diverted from X to Z, or from Z to X, with the help of the slip points and this arrangement is known as a *single slip*. If the train is also required to pass from W to Y, or Y to W, two more pairs of switches, shown dotted, are installed and the layout is called a *double slip*. The smaller the crossing angles B and D, the flatter is the slip curve KH.

(*8*) If two crossovers are required between two parallel tracks and if there is insufficient space for the crossings to be kept separate, they are made to overlap, and the result is a *scissors crossover* (Fig. 814). It consists of four turnouts AB, CD, EF and GH and a diamond *abcd*, with necessary connections. The diamond is normally equidistant from the two tracks, but if the distance between the points A and H is to be reduced on one track, the diamond is placed closer to this track. This results in an increase in length of the distance between points E and D on the other track.

(*9*) When turnouts are required from a central track to tracks on either side of it, and if the space for these turnouts is limited, recourse is had to a *double turnout* (Fig. 815). In this arrangement, the points BT of the second turnout are laid immediately behind points AL of the first turnout and the two turnouts cross each other by a third crossing C. The two crossings D and E may be of the same angle, but crossing C has to be of a special angle, depending on the set back of points BT from points AL. Sometimes the stock rails of points AL are connected directly to the stock rails of points BT.

(*10*) An earlier version of the double turnout was the *three-throw switch*. Its function was the same as that of a double turnout. The difference between the two types of layouts lies in the staggering of the points in the double turnout. The three-throw switch has only two stock rails and each switch has two tongue rails with combined heel blocks for both tongues. The arrangement is weak at the heel of switch and there are difficulties in obtaining correct gauge on all tracks at the toe of switch. This type of layout is not much used.

(*11*) When a number of parallel lines ABC (Fig. 702*c*) are

to be connected together, so that they may be accessible from a main track M, the connecting line is called a *gathering line*. The gathering line may be diagonal to the sidings, as at DE, or parallel to the sidings, as at FG. In the latter case, it forms part of the main track. With a diagonal gathering line, the length of the siding decreases as its distance from the main track increases and the

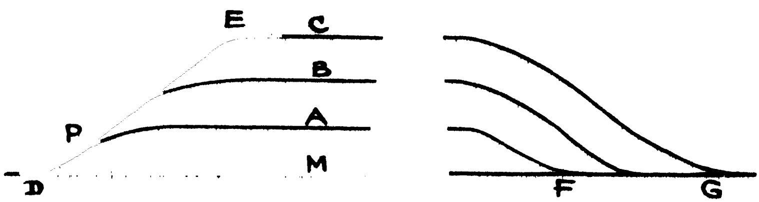


Fig. 702*c*

reverse is the case with a parallel gathering line. Hence, if all sidings are to be made of equal length, a diagonal gathering line is laid at one end and a parallel gathering line at the other end.

Gathering lines may be laid at any angle, varying from the angle of the *crossing* to the *limiting angle*, the shortest possible length being obtained in the latter case. The limiting angle is such that its sine is equal to $\dfrac{\text{the distance between two adjacent tracks}}{\text{the overall length of the points and crossing}}$. The limiting angle varies with the track spacing and with the overall length of the points and crossings. Gathering lines cannot be laid at angles less than the crossing angle, or greater than the limiting angle.

It is usual to lay gathering lines at the limiting angle, as this gives the most economical layout. A gathering line at the crossing angle, although wasteful of space, is useful when dealing with fast traffic, as it gives smoother running, due to the straights between curves, and due to the crossing angle being small.

There are several other variations, such as laying of the gathering line at an angle equal to twice the crossing angle, and connecting two sidings from each turnout off the gathering line. The angle of the gathering line may also be increased to three times the crossing angle and three sidings may be connected to each turnout leading off the gathering line. These are devices for saving space, as with such arrangement the space occupied is even less than that taken up by a gathering line at a limiting angle.

703. Design of crossings

The size of a crossing is expressed in terms of the distance required in spreading the point and splice rails by one foot. The spread is measured between the gauge faces of the rails. If the spread between the point and splice rails at a distance of 12 feet from the nose of crossing is 1′, the size of the crossing is 1 in 12.

A crossing with a sharp angle provides a smooth passage for a train negotiating the turnout, as the lead is long, but due to this long lead, the turnout takes up more space than one with a crossing of wider angle.

Crossings with sharp angles are used on tracks where high speeds prevail and crossings with wider angles are used on sidings. In India, the standard sizes are 1 in 8½, 1 in 12 and 1 in 16. For symmetrical splits, 1 in 6 crossings are also used. In Britain, crossings used are of sizes 1 in 6, 8, 10, 12 and 16; sizes 1 in 24 and 1 in 28 are also used. In America, crossings of sizes ranging upto 1 in 24 are employed. The reason for the variation lies in the safe speed over turnout. No restriction in speed is necessary on the straight track of a turnout, provided the points are adequately prevented from moving whilst a train passes over them. The speed on the curved track has, however, to be severely restricted, due to the sudden change in the direction in which a train is travelling and due to absence of superelevation on the curved portion of the turnout.

For BG track in India speeds of 20, 15 and 10 m.p.h. are considered the limits for 1 in 16, 1 in 12 and 1 in 8½ turnouts respectively. For MG track the corresponding speeds are 18, 14 and 10 m.p.h. respectively.

There are two methods of working out permissible speeds over turnouts. One is to ascertain the virtual curve with the heel divergence as the versine.

The second method, which is felt to be more accurate, is to consider the thrust obtaining at the toe of the switch due to the sudden change in the direction of motion. The versine over a chord length equal to the bogie centres and for the curvature of the virtual curve connecting ends of the chord is taken as the thrust, allowance being made for 100 per cent impact by halving the radius. With these conditions the maximum versine occurs at the toe of the switch.

The radius of the virtual curve having been ascertained, the speed corresponding with permissible cant deficiency (para 1309)

is obtained The speed over a standard Indian 1 in 16 turnout is obtained as follows

Versine at toe of switch with a chord of 48′, i e distance of bogie centres, is 1.8″

$$\text{Versine} = \frac{c^2}{8r}$$

$$\frac{1\ 8}{12} = \frac{48^2}{8r}$$

hence r, the radius of versine curve = 1920

This is to be halved to account for impact

Permissible cant deficiency being 3″

$$c = \frac{gv^2}{1\ 25r}$$

$$3' = \frac{5\ 5v^2}{1\ 25 \times 960}$$

hence x = 25 58 m p h

The recommended speed is 20 m p h

In Britain a speed of 50 miles per hour over the turnout is considered reasonable for a 1 in 24 crossing with 24′-6¾″ long curved switches, whilst for a 1 in 28 crossing with a 40′-10$\frac{7}{16}$″ curved switch, a reasonable speed is considered to be 70 miles per hour Crossings flatter than 1 in 20 are not fabricated from rails but are cast in high manganese steel

In America, about 30 to 35 miles speed is permitted on a 1 in 20 crossing, and a speed of 15 miles per hour is considered suitable for a 1 in 10 crossing With 1 in 24 crossings with 39 feet long switches, when laid as symmetrical splits (*vide* para 803), speeds upto 83 miles per hour are permitted (the safe speed is calculated at 119 miles per hour) provided the centre of gravity of trains lies within 7 feet above rail level

A rough rule is to keep the permissible speed in miles per hour less than twice the number of the crossing According to this, speed over a 1 in 10 crossing should be kept below 20 miles per hour

The *angle of a crossing*, defined in para 701, varies with the method of setting out this angle when the crossing is manufactured There are three ways of setting out the crossing angle, as shown in Fig 703*a* In one case, a right-angled triangle is used, in the remaining cases isosceles triangles are used, the measurement being

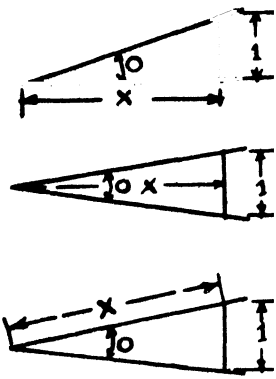


Fig. 703*a*

along either (*1*) a line bisecting the crossing angle or (*2*) one of the two equal sides of the isosceles triangle. The three methods of measuring the crossing angle are sometimes known as the *right-angle*, the *centre-line* and the *isosceles* methods. The values of the crossing numbers in terms of the crossing angle, o, in the three cases, are as follows : In the right-angle method, the value of the crossing number is x cot o. This is the standard method in use in India and gives the smallest crossing angle. In the centre-line method, common in Britain and America, $x=\frac{1}{2}\cot\frac{o}{2}$. The isosceles method is used for tramways and in this $x=\frac{1}{2}$ cosec $\frac{o}{2}$. Following are the values of the crossing angle o of a 1 in $8\frac{1}{2}$ crossing, namely, where $x=8\frac{1}{2}$, and illustrate the difference in crossing angle obtained by the three methods:

$$6^\circ\ 42'\text{-}35'' \ — \ 6^\circ\ 43'\text{-}59'' \ — \ 6^\circ\ 44'\text{-}41''$$

For all formulæ the first method only, i.e. where $x=\cot o$, is adopted in this book, as it is the standard Indian method. Confusion is likely to result if formulæ worked out for one method are applied to another method.

The simplest way to ascertain the number of an acute crossing in the track is to measure the length of the crossing ER in Fig. 701 and divide it by the sum of the spread at each end, i.e. GE plus RS. The angle of an obtuse crossing is found in the same way. There are other equally simple methods, such as measuring the distance from the theoretical nose of the crossing to a point where the spread is one foot, the figure (in feet) thus obtained being equal to the number of the crossing. The length of the crossing body depends mainly on structural considerations, but it should not be so short as to rock under traffic, nor so long as to naturally shorten, and thereby sharpen, the lead curve connecting it to the switches. The lengths of the standard crossings in India are 19'-7" for broad gauge 1 in 12 and 22'-11¾" for 1 in 16 crossing; 15'-9" for 1 in 8½ broad and 1 in 12 metre gauge crossings.

The *theoretical nose* is the point where the gauge face lines RE and SG cross (Fig. 701), and is a little ahead of the actual nose, as the nose would be too slender if brought to a fine point. The nose is kept about ¾" thick in practice.

The space between the point and wing rails is governed by the profile of the wheels. At the throat, the clearance is slightly greater, as the wing rail cannot be bent to a sharp point opposite the throat.

When a wheel passes from the wing rail to the point or splice rail, it has a tendency to jump on the nose of the crossing. The latter is thereby damaged in a short time. To avoid this, the wing rail, instead of having a flat surface, is ramped, so that the surface of the wing rail is $\frac{1}{8}''$ higher than the surface of the nose. As wheels are coned, this ramped wing partly supports the wheel, whilst the load is being transferred to the point or splice rail and this avoids impact on the point or splice rail. Another method adopted in Britain, of avoiding impact on the nose, is to plane it down below the surface of the wing rail.

A check rail is so fixed that about two-thirds its length is ahead of the crossing nose. It is splayed out at each end and the clearance is gradually reduced to the required clearance opposite the nose. This enables the wheel flange to be guided smoothly through the flange space.

The weakest part of the crossing lies between the throat and a short distance behind the nose. Heavy wear occurs on point, splice, and wing rails in this length. Due to the rapid wear of these parts, crossings had to be renewed frequently, even though the remaining parts of the crossings were perfectly sound. To avoid this, inserts of special hard alloy steels are sometimes introduced, but a more favoured method is to build up these worn parts by welding. By welding the worn parts at a very small cost, the crossings are made fit for considerable further service. The maximum vertical wear permitted before renewal or reconditioning on a wing rail is limited to $\frac{3}{8}''$.

In order to prevent a vehicle from lurching at the throat, spring crossings are used in main line turnouts in Britain and America. In a spring crossing (Fig. 703*b*), one wing rail A is fixed and the opposite wing rail B, which is slightly longer than A, slides

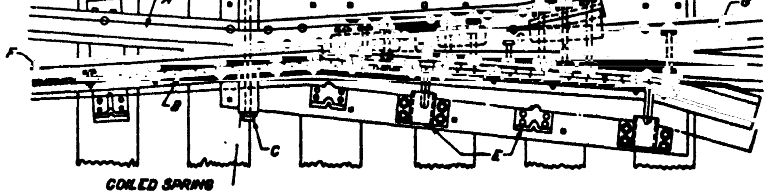


Fig. 703*b*

on a plate D between the splice rail and stops E. The sliding wing is normally held to splice rail with a strong spring C, and provides a continuous rail for the main track FG. When the turnout track is negotiated, the sliding wing is pushed against its stops by wheel flanges. Spring crossings are used to best advantage where there is high speed traffic on the main track and very light traffic on the turnout line. They are usually employed in (*1*) turnouts from double line, in a trailing direction, over which traffic is light, and (*2*) emergency crossover on double line.

704. Design of switches

In Fig. 701 the distance JY between the gauge face of the stock and tongue rails is the *heel divergence*. Its value depends on the flange clearance and the width of the rail head. For broad gauge, it varies from 5¼″ to 5⅜″. The angle YHJ is the switch angle and its value depends on the heel divergence and the length of the tongue. The smaller the switch angle, the smoother is the running over the turnout. In America the switch angle is not allowed to exceed one-fourth of the crossing angle. The length of the switch is governed by the maximum rigid wheel base of vehicles. If switches are shorter than the rigid wheel base, the toe of the switch is likely to tip up when the sleepers under the heel are not fully packed. This may possibly be a cause of derailment. On the other hand, when straight switches are used the lengthening of the switch makes the lead curve GJ sharper and this is undesirable. The standard lengths of switches used in India are 32′ for BG and 24′-4″ for M.G. with 1 in 16 crossings; 21′ for broad and 18′ for metre gauge with 1 in 12 crossing; 15′-6″ for broad and 13′-6″ for metre gauge with 1 in 8½ crossings. Curved switches are used with 1 in 16 crossings and straight switches with 1 in 12 and 1 in 8½ crossings. Stock rails are kept longer than tongue rails to prevent any joints between the toe and heel of the tongue rail. The stock rail PD on the turnout side has to be kinked slightly at the toe of the switch to prevent tight gauge. This is done with a jimcrow after laying the points, and the kink is made about 6″ ahead of the toe.

Switches are of two types, the *loose heel* type and the *fixed heel* type. In the loose heel type, the tongue ends at the heel of switch and in order to enable the free end of the tongue to be moved, the heel block bolts which are threaded through the tongue rails have to be kept slightly slack and the inner fishplates have to be bent slightly. To prevent the nuts from working loose, split pins are sometimes inserted through holes in the nuts and bolts. This looseness of the heel is a weakness in the structure. One way of improving this is to use *Alexander heel fulcrums* which grip the heel of the tongue between two fulcrum pieces of semi-cylindrical

shape. These fulcrum pieces are housed in recesses in the heel block and the inner fishplate. The semi-cylindrical fulcrum pieces allow the heel to rotate and at the same time hold it rigidly to the stock rail. Another method of overcoming the difficulty is to use fixed heels. The tongue rail in this case does not end at the heel block but is extended beyond it; the movement at the toe of switch is made possible by the flexibility of the tongue rail. Sufficiently flexible tongue rails made out of flat-footed rails can only be obtained by making the tongue of considerable length. This difficulty does not arise with bull-headed rails. Smoother riding over the turnout portion is obtained by curving the tongue rail JH on the straight side and the stock rail PD on the turnout side. With curved stocks and tongues, separate switches are necessary for right hand and left hand turnouts and the switches are not interchangeable. In India and America straight switches are mostly used, whilst in Britain curved switches with fixed heel are in vogue. In India, fixed heel type switches are now used.

All tongue rails are given side support by means of *studs* or other forms of projection from the stock rail, to prevent their being bent by the lateral thrust of wheel flanges.

The former method of housing a tongue rail in a stock rail was to plane down one flange each of the stock and the tongue rails and also the head of the tongue rail, gradually towards the toe. The tongue rail was thereby brought as close to the stock rail as required and the web of the tongue rail at the toe was housed under the head of stock rail. This was known as the *undercut switch*. The planed stock rails were, however, weak and the tongue rails wore down rapidly. The present standard switch, in India, has a tongue rail of section smaller than that of the stock rail. The tongue rail slides over the foot of the stock rail and over packing pieces beyond the foot of the stock rail. This arrangement is known as the *overriding switch*. The section of the stock rail is not reduced and a further improvement is to hump the tongue rail slightly above the head of the stock rail, to prevent the false flange of a worn wheel from wedging between the stock and tongue rails. A wheel develops a false flange towards its outer face when the centre portion of the tread is considerably worn. In Britain, *chamfered switches* are used for their high speed points which permit speeds of over 50 m.p.h. over the turnout. In the chamfered switch the head of the stock rail is undercut to house a thicker section of tongue rail, thereby making the long tongue rails stronger.

With bull-headed rails, the toe of the tongue can also be housed in a kink or "joggle" made in the stock rail. This is not possible with flat-footed rails.

Points and Crossings : Various Layouts and Maintenance

801. Calculations for various layouts

DETAILS of all connections which are normally used are given. Several variations of these connections are possible, but calculations of all possible variations would fill a book. For all complicated layouts, the simplest method is to make a large-scale

drawing and obtain all measurements from this drawing. In India, most of the combinations have been standardized and the exact measurement of each part is available in the Permanent way Manual issued by the Research, Designs and Standards Organisation of Indian Railways in India. Appendix G gives a few important dimensions.

802. Connection of switches and crossings

In Fig. 802*a*, AC is the switch, C being the heel and BD is a part of the crossing body from toe D to nose B. If the distance ED, between the heel C and the nose D and parallel to the straight track, is known and the radius of the connecting curve CD is also known, the points and crossings can be set out. It may be noted that the lead, as defined in para 701, is equal to the connecting lengths plus $e \cos o$, where e is the length from toe to nose of crossing and o is the crossing angle.

$$\text{Distance DE} = \text{CE} \cot \frac{o+s}{2} \ldots\ldots\ldots\ldots\ldots (1)$$

in which CE equals $(g - h - e \sin o) \ldots\ldots\ldots\ldots (2)$

g being the gauge, h the heel divergence, e the distance, toe to nose of crossing, and s the switch angle.

Proof

Angle CDE $= \dfrac{o+s}{2}$ as follows :

$\angle$ JFA $= \angle$ HAF $= s$ since FJ is drawn parallel to AH.

$\angle$ HFJ $= \angle$ FBK $= o$ „ FJ is „ „ to BK.

hence $\angle$ HFC $= (o - s)$

$\angle$ CFD $= 180 - (o - s)$

and since FD $=$ FC since they are tangents to the curve DC, $\angle$ FCD $= \angle$ FDC.

and each is equal to

$$\frac{1}{2}\left[\, 180^\circ - [\, 180^\circ - (o - s)\,]\,\right] = \frac{o-s}{2}$$

$\angle$ CDE $= \angle$ FDE $- \angle$ FDC

$$= o - \frac{o-s}{2} = \frac{o+s}{2}$$

Formula (2) is obvious from the figure and needs no proof. The radius r of the connecting curve

$$= \frac{CE}{\cos s - \cos o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

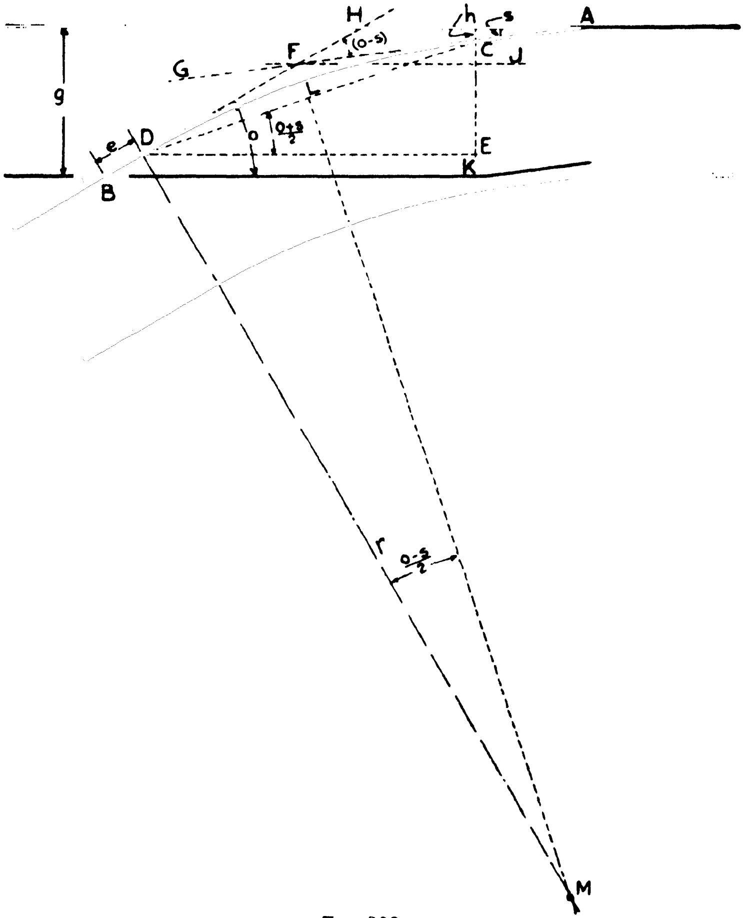


Fig. 802*a*

Note—In all formulæ the radius is taken, not to the centre of the curved track, but to the running edge of the outer rail.

Proof

LM and DM are drawn perpendicular to DC and FD respectively, L being the centre of DC. Since DC is the chord and FD a tangent of curve DC, DM is the radius of the curve.

Due to DM and LM being perpendicular to DF and DC respectively.

$\angle$ DML = $\angle$ FDC which had already been proved to be equal to $\frac{o-s}{2}$

$$r = \frac{DL}{\sin \angle DML} = \frac{DL}{\sin \frac{o-s}{2}}$$

$$\text{and } DL = \frac{1}{2}\ DC = \frac{1}{2} \cdot \frac{CE}{\sin CDE}$$

$$= \frac{1}{2}\ \frac{CE}{\sin \frac{o+s}{2}}$$

$$\text{Hence } r = \frac{CE}{2 \sin \frac{o-s}{2} \sin \frac{o+s}{2}}$$

$$\text{and since } 2 \sin \frac{o+s}{2} \sin \frac{o-s}{2} = -(\cos o - \cos s)$$

$$r = \frac{CE}{\cos s - \cos o}$$

The connecting length DE is slightly different, if the turnout is taken off a curve, but the difference is so small that the same connecting length is taken in all cases. The lead, which is equal to the connecting length plus ($e \cos o$), must, in all cases, be measured from the theoretical nose of the crossing, at right angles to the line connecting the two heels of the switches.

If the connection is on the outside or inside of a curved track, the radius of the connecting curve in each case is different to that given above. These radii are however easily obtained by conversion of radii into degrees of curvature. When the connection is on the outside of a curve the degree of the connecting curve equals the degree of connecting curve from a straight track minus the degree of the main line curve. If the connection is on the inside of a curved track, the degree of the connecting curve equals the degree of the connecting curve from a straight track plus the degree of the main line curve. This imposes limits on the size of the crossing, which can be used on curves, due to imposition of limits on the maximum degree of the curves (i.e. 10° for broad gauge). For example, assuming the degree of the connecting curve from a straight

track to be 8° for a 1 in $8\frac{1}{2}$ crossing, the main line curve on the inside of which a 1 in $8\frac{1}{2}$ crossing may be used is 2° since (2°+8°=10°) and the degree of the connecting curve will then be 10°. It is usual to lay crossings with small crossing angles (i.e. large crossing numbers, e.g. 1 in 12) on the inside of a main line curve and crossings with large crossing angles (e.g. 1 in $8\frac{1}{2}$) on the outside of a main line curve.

The lead curve is usually set out with offsets from the rail AP (Fig. 802*b*) of the straight track. The offset at any point N, at

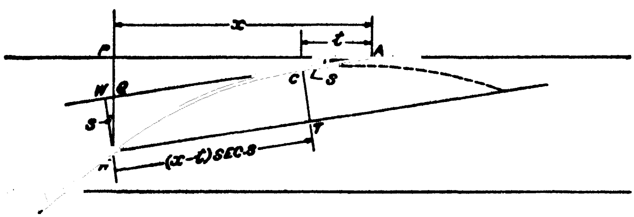


Fig. 802*b*

a distance x from toe of switch A, is NP and this is equal to PQ plus QN.

$$PQ = x \tan s \text{ and } QN = \frac{WN}{\cos s}$$

$$WN = CT = \frac{NT^2}{2r} = \frac{[(x-t)\sec s]^2}{2r}$$

$$\text{hence } QN = \frac{[(x-t)\sec s]^2}{2r \cos s}$$

$$\text{and the offset } NP = x \tan s + \frac{[(x-t)\sec s]^2}{2r \cos s}$$

803. Symmetrical split or equilateral turnouts

In a symmetrical split, as both tracks have equal curvature, the degree of curvature of each curve is half, and the radius is therefore double that of the curve in a turnout from a straight track.

The connecting length of a symmetrical split is obtained as follows:

In Fig. 803, UV is the centre line of the symmetrical split and DE is the connecting length.

Since UV bisects the crossing angle o and ZA bisects the switch

$$\text{angle } s \text{ the angle CDE} = \frac{o/2 + s/2}{2} = \frac{o+s}{4}$$

The proof is similar to that given in para 802 and Fig. 802*a*.

The connecting length DE $= \text{CE} \cot \dfrac{o+s}{4}$.

$$\text{where CE} = g/2 - h/2 - e\,\frac{\sin o}{2}$$

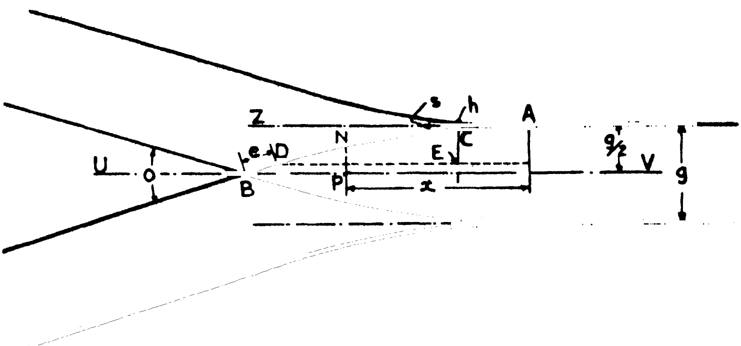


Fig. 803

For setting out a symmetrical split, offsets are measured from the centre line UV. The offsets, at any distance x from the toe of switch is obtained by deducting from $g/_2$ the offset from the line ZA. The value of the offset from ZA is $x \tan\dfrac{s}{2} + \dfrac{(x-t)^2}{2r}$.

The value of this offset is the same as that given for NP in para 802 but with s replaced by $s/_2$. As however angle $s/_2$ is very small, the values of sec s and cos s may be taken as 1, with the resulting above value for offset from ZA.

The offset NP (Fig. 803) at any distance x is therefore

$$\frac{g}{2} - \left[x \tan\frac{s}{2} + \frac{(x-t)^2}{2r} \right]$$

804. Crossover between parallel tracks

In Fig. 804 the only dimensions necessary for the layout of the crossover is distance a between the theoretical noses of the two crossings

$$a = BD = CB \cot o$$

$$CB = AB - AC = (g - w) - AC,$$

where g is the distance between tracks and w the gauge.

$$AC = AE \sec o = w \sec o$$

where AE is drawn at right angles to LA

$$\text{Hence } a = (g - w - w \sec o) \cot o.$$

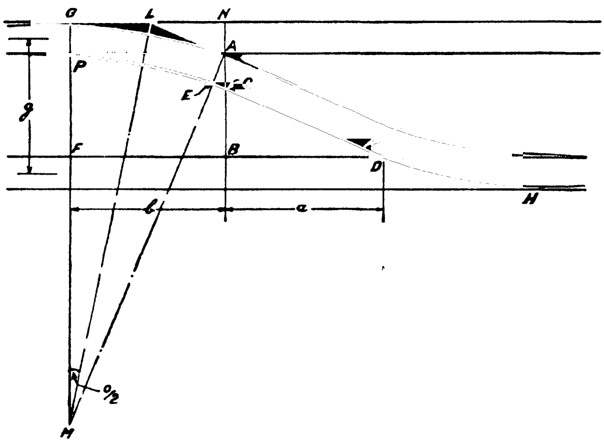


Fig. 804

805. Crossover between parallel curved tracks

In Fig. 805 the distance a has the same value as a in Fig. 804. The degree of curve A is the same as the degree of main line curve.

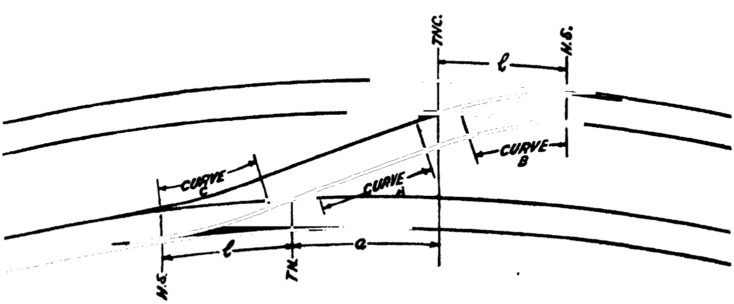


Fig. 805

The degree of curve B equals the degree of main line curve plus the degree of lead curve. The degree of curve C is the degree of main line curve minus the degree of lead curve.

806. Turnout to a parallel track

In Fig. 804 the portion to the right of NA and the switch to the left of GP are to be ignored in considering the figure as a turnout. In this figure if the distances DB and BF are obtained, the turnout can be set out. The turnout curve AG is made of the same radius as the lead curve DH.

The length a is the same as that of the crossover.

$$\text{Hence } a=(g-w-w \sec o) \cot o$$

The length $b=\text{GL}+\text{LN}=t+\text{LN}=t+\text{LA} \cos o=t(1+\cos o)$ since LA=GL.

By reasoning similar to that given in para 802 (Fig. 802a) angle LMA $= \dfrac{o}{2}$ hence LA $=t=r \tan \dfrac{o}{2}$ and from the value of t, the value of b is obtained.

807. Turnout to a divergent track when the angle of divergence is greater than the crossing angle

In Fig. 807 the radius of the connecting curve EB is taken the same as that of the lead curve. The angle of divergence p is known or is measured.

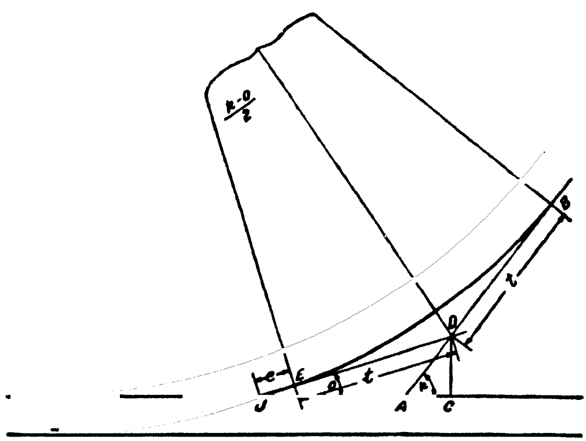


Fig. 807

The turnout can be laid, if the distances JA and AB are determined.

By reasoning similar to that given in para 802,

angle $\quad ELD = \frac{o-p}{2}$ hence $t = r \tan \frac{p-o}{2}$

$$JA = JC - AC$$
$$= (e+t) \cos o - AC$$
$$AC = DC \cot p \quad \text{but as } DC = (e+t) \sin o$$
$$AC = (e+t) \sin o \cot p$$

hence
$$JA = (e+t) \cos o - (e+t) \sin o \cot p$$
$$= (e+t)(\cos o - \sin o \cot p)$$

also
$$AB = BD + DA = t + DA$$

where
$$DA = DC \operatorname{cosec} p$$
$$= (e+t) \sin o \operatorname{cosec} p$$

hence
$$AB = t + (e+t) \sin o \operatorname{cosec} p$$

808. Turnout to a divergent track where the angle of divergence is less than the crossing angle

In Fig. 808 the two diverging tracks are connected with a straight BC and a curve CE. The radius of the curve CE is taken

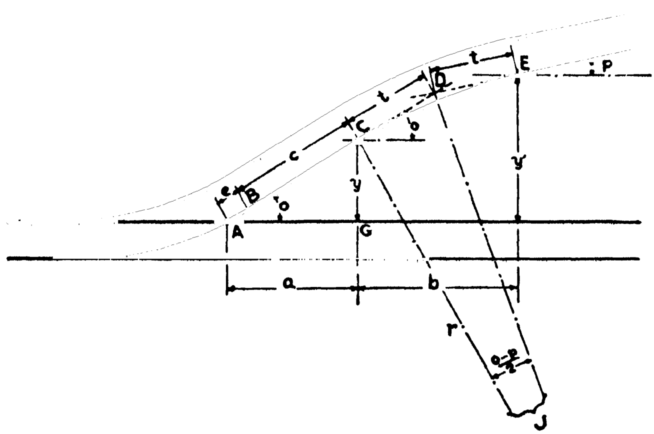


Fig. 808

the same as the radius of the lead curve. The angle p between the two tracks is known and the length of the straight BC, i.e. c is

arbitrarily fixed. The distances a and b and the offsets y and y' determine the connection.

The angle CJD $= \frac{o-p}{2}$ by reasoning similar to that of para 802.

$$a = (c + e) \cos o$$
$$y = (c + e) \sin o$$
$$b = t \cos o + t \cos p = t (\cos o + \cos p)$$

where $t =$ CJ tan DJC $= (r-w) \tan \frac{o-p}{2}$

where $w =$ gauge

$$y' = (e + c + t) \sin o + t \sin p$$

809. Crossovers between diverging tracks

Crossovers between diverging tracks may be in the direction AB or KL (Fig. 809). The crossover in the direction KL may be treated as two separate turnouts, one from track BK and another from track AL, to divergent tracks and dealt with as in para 807.

When the crossover is in the direction AB, the distance y has to be assumed. The radius of the curve DB is taken the same as that of the lead curve and the crossings at A and B are taken of the same angle. Distances a, b and x are required.

$$a = \text{FQ}-\text{FA} = y \cot o - w \operatorname{cosec} o$$

where w is the gauge

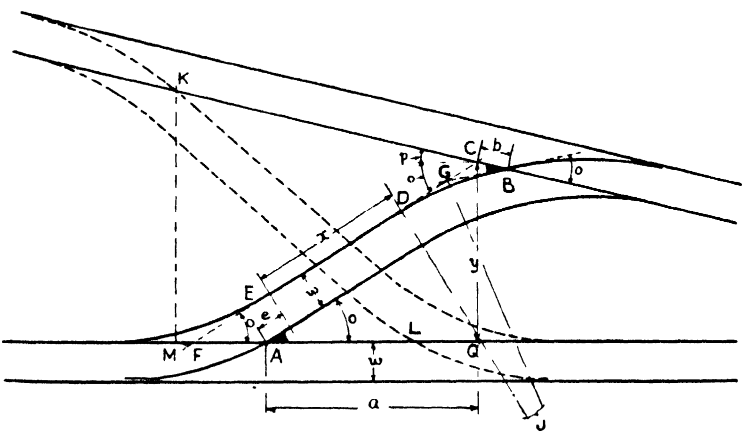


Fig. 809

Angle KCG $= o + p$ hence angle GCB $= 180° - (o + p)$ also angle CGB $= p$ where p is the angle between tracks AB and KL

$$\frac{CB}{\sin CGB} = \frac{GB}{\sin GCB}$$

namely, $$\frac{b}{\sin p} = \frac{t}{\sin 180° - (o + p)}$$

$$= \frac{t}{\sin (o + p)}$$

hence $$b = \frac{t \sin p}{\sin (o + p)}$$

$$= t \sin p \operatorname{cosec} (o + p)$$

where $t = r \tan \frac{p}{2}$, since GB $=$ DG and angle DJG$= \frac{p}{2}$

$$x = FC - FE - DG - GC$$

From triangle CGB

$$\frac{GC}{\sin CBG} = \frac{BC}{\sin CGB}$$

Therefore GC $= b \sin o \operatorname{cosec} p$

FC $= y \operatorname{cosec} o$

DG $= t$

FE $= w \cot o + e$

where e is the distance from nose to heel of crossing

hence $x = y \operatorname{cosec} o - (w \cot o + e) - t - (b \sin o \operatorname{cosec} p)$

810. Gathering lines

The calculations for a gathering line at the *crossing angle* (*vide* para 702.11) are very simple. The dimensions required (*vide* Fig. 810*a*) are a and b

$$a = g \cot o \text{ and } b = g \operatorname{cosec} o$$

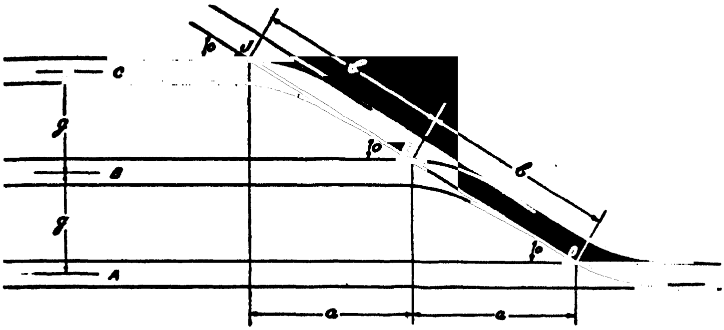


Fig. 810*a*

A gathering line at a *limiting angle* (*vide* para 702.11) is shown in

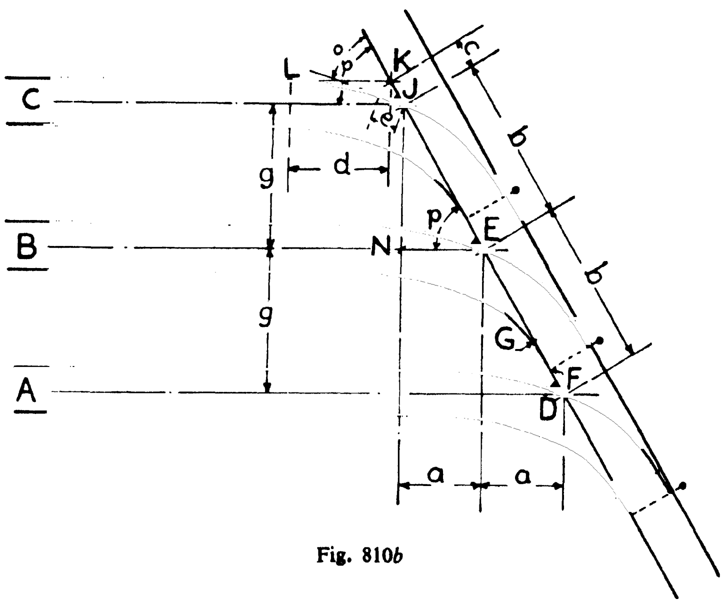


Fig. 810*b*

Fig. 810*b*. In this case, the limiting angle has first to be found and besides the lengths *a* and *b*, lengths *c* and *d* are also necessary.

Since the object of using the limiting angle is to save all possible space, ends of switches of turnout E are joined to the heel of crossing of turnout D. The length *b* is therefore equal to the distance, nose

to heel of crossing (i.e. DF), plus length of switch, namely, end of stock rail to heel of switch (FG), plus the lead GE of the turnout. All these values are known, hence b is known.

The limiting angle p is obtained from

$$\sin p = \frac{JN}{JE} = \frac{g}{b}$$

$$\text{also } a = NE = JN \cot p = g \cot p$$

The connection at J may be treated as a turnout to a diverging track and KJ and KL are therefore the same as AJ and AB of Fig. 807. The values of c and d are therefore

$$c = (e + t)(\cos o - \sin o \cot p) \text{ same as JA of Fig. 807}$$

$$\text{and } d = t + (e + t) \sin o \operatorname{cosec} p \text{ same as AB of Fig. 807.}$$

The connections at E and D are treated similarly.

811. Diamond crossings

In Fig. 811, the distance HC, CB and JD are required to determine the positions of the two acute and two obtuse crossings. Their values are $CB = BD = DA = AC = w \operatorname{cosec} o$ where w is the gauge.

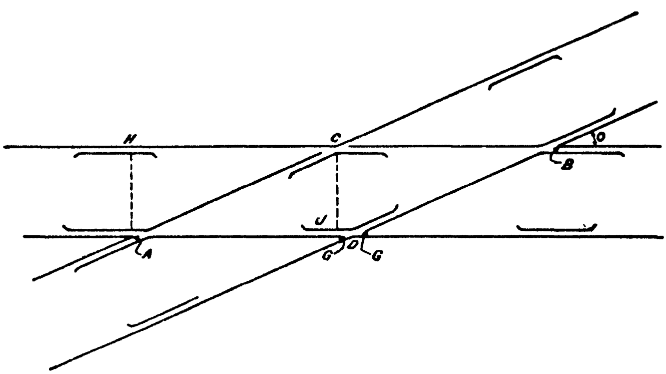


Fig. 811

$$HC = w \cot o$$

$$JD = CB - HC = w(\operatorname{cosec} o - \cot o).$$

812. Slips

In Fig. 812 the ends of stock rails of switches JK and GH are connected to the heel of crossings B and D, at J and G respectively, and a curve KH connects the heel of switches at K and H.

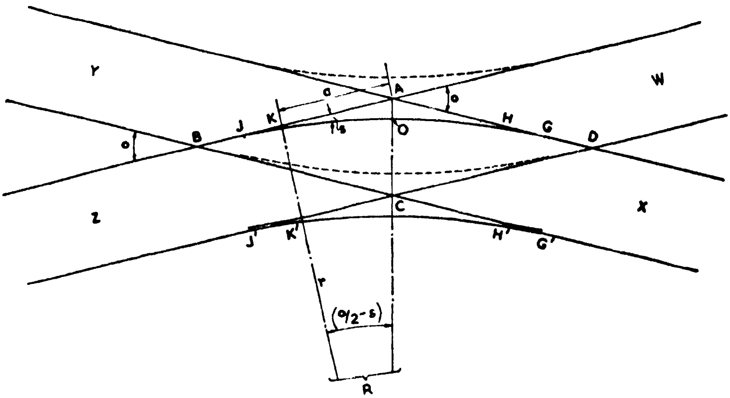


Fig. 812

The radius r of this curve KH, and the distance from A of the centre point Q of the curve, are necessary to determine the layout.

$$r = \text{KR} = \text{KA} \cot \text{KRA}.$$

KA = AB — BK and as the value of AB is found as per para 811 and BK = the distance from nose to heel or crossing, plus end of stock rail to heel of switch, the value of KA is found.

By reasoning similar to that of para 802,

$$\text{angle KRA} = \left(\frac{o}{2} - s\right)$$

The distance AQ = AR — QR

$$\text{AR} = r \sec\left(\frac{o}{2} - s\right) \text{ and QR} = r$$

$$\therefore \text{AQ} = r\left[\sec\left(\frac{o}{2} - s\right) - 1\right]$$

813. Double junctions

For the location of double junctions (Fig. 813) the distance *a*, *b*, *c* and *d* are required and these are easily obtained from the figure as follows:

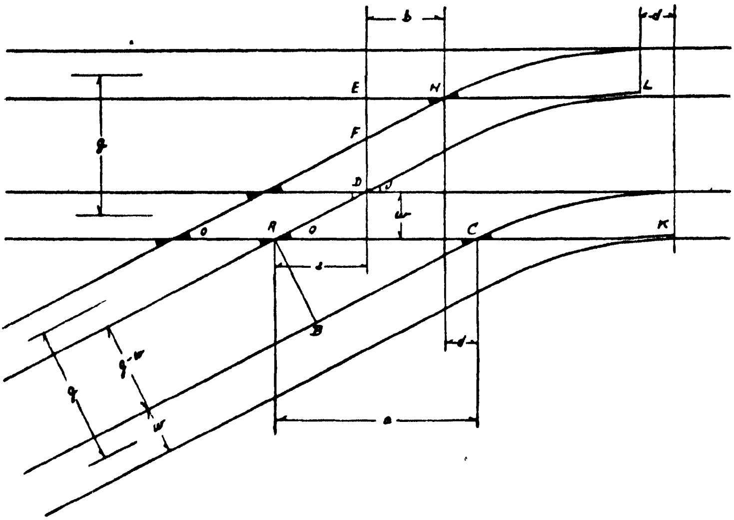


Fig. 813

$$a = \text{AB cosec ACB}$$

$$= (g—w) \text{ cosec } o$$

$$b = \text{EF cot } o = (\text{ED—FD}) \text{ cot } o$$

but $\text{ED} = (g—w)$ and $\text{FD} = w \text{ cosec } o$

hence $b = (g — w — w \text{ cosec } o) \text{ cot } o$

$$c = w \text{ cot } o$$

d, namely the distance of points K ahead of $\text{L} = a — b — c$

814. Scissors crossover

The scissors crossover (Fig. 814) is symmetrical about the lines XX and YY. In order to fix the positions of the four crossings

and the diamond abcd, the length bc of one side of the diamond and the distances zc, zb and fg are required.

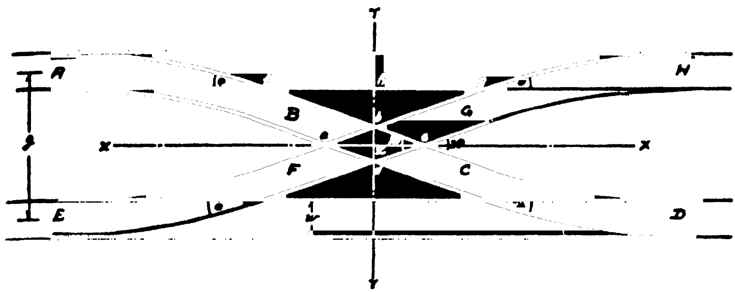


Fig. 814

$$bc = w \operatorname{cosec} 2o$$

where w is the gauge

$$zc = bc \cos o = w \operatorname{cosec} 2o \cos o$$

$$zb = bc \sin o = w \operatorname{cosec} 2o \sin o$$

$$fg = 2hg = 2hb \cot o$$

where $hb = zh - zb = 1/2\,(g - w) - zb$

$$= 1/2\,(g - w) - w \operatorname{cosec} 2o \sin o$$

815. Double turnout

In a double turnout (Fig. 815), the switch BT is fixed immediately behind switch AL, hence the distance a is equal to the length of the stock rail. The crossings at D and E are taken of the same angle, either 1 in 12 or 1 in 8½. Since the degree of curve of a 1 in 12 turnout is the same as that of a 1 in 8½ symmetrical split, the crossing at C will be 1 in 8½ if the crossings at D and E are 1 in 12. Similarly with 1 in 8½ crossings at D and E, crossing C will be 1 in 6.

If in Fig. 815, distances b and c are determined, the connection can be laid out.

Since FC is a half chord and FL the versine

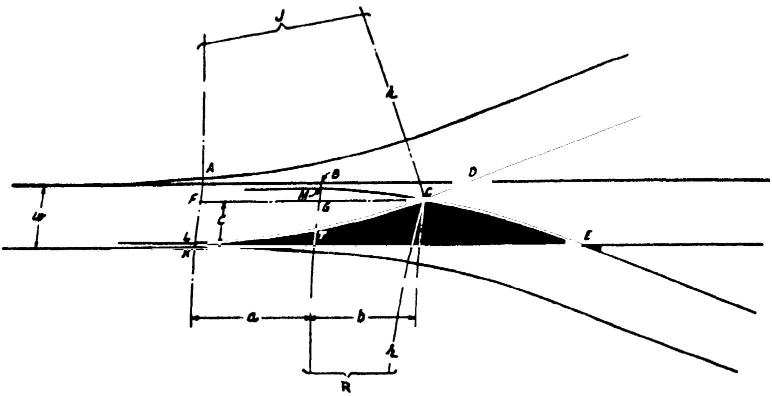


Fig. 815

$$FL = \frac{FC^2}{2r}$$

$$c - d = \frac{FC^2}{2r}$$ where d is the heel divergence

$$i.e.\ c = \frac{FC^2}{2r} + d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The lead curve CL has been assumed to start at C, although it should start at the toe and not at the nose of the crossing. The error due to this assumption is negligible.

Similarly $BG = \dfrac{GC^2}{2r}$

namely $w - c - d = \dfrac{GC^2}{2r}$

$$c = w - d - \frac{GC^2}{2r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Equating (1) and (2)

$$\frac{FC^2}{2r} + d = w - d - \frac{GC^2}{2r}$$

since $FC = (GC + a)$

$$(GC + a)^2 + 2rd = 2rw - 2rd - GC^2$$

$$GC^2 + aGC + \left(2rd - rw + \frac{a^2}{2}\right) = 0$$

hence $$GC = \frac{-a \pm \sqrt{4\left(2rd - rw + \dfrac{a^2}{2}\right)}}{2}$$

$$= -\frac{a}{2} \pm \sqrt{2rd - rw - \frac{a^2}{4}}$$

As all items on the right hand side of the equation are known the value of GC or b is obtained

$$\text{and } c = \frac{(a+b)^2}{2r}$$

The distance AD is the lead of an ordinary turnout (*vide* para 802).

816. Three-throw switch

Since in a three-throw switch, AL and BT (*vide* Fig. 815) coincide, crossings D and E are opposite each other and the distance $c = \frac{w}{2}$

$$\text{As BG} = \frac{\text{GC}^2}{2r} \text{ where BG} = \frac{w}{2} \text{ and GC} = b$$

$$b^2 = \frac{2rw}{2} \text{ or } b = \sqrt{rw}$$

817. Method of laying points and crossings

The only economical way of introducing various connections during the construction of a new railway is to build them up at site as the problem of reopening the track for traffic with the least possible delay does not arise. Accurate measurements are essential for satisfactory connections and no approximations should be permitted.

The laying or renewing of various connections in a track, already in use, is done in three different ways : (*a*) The connection may be built up at site or (*b*) it may be laid out on an adjoining plot and rolled or slid complete into position or (*c*) the connection may be built up at a depot, dismantled after the corresponding parts are carefully marked and built up again at site. Sometimes methods (*b*) and (*c*) are combined by having the connection built up at a depot, divided into a few convenient complete units, conveyed to the site in wagons and laid in the track with the help of a crane.

For simple connections such as ordinary turnouts and crossovers, method (*a*) is commonly adopted unless heavy traffic on the track concerned does not allow sufficient time for the work. In the latter case method (*b*) is adopted.

For complicated layouts, it is advisable to build them up complete before laying them in the track and method (*b*) or (*c*) or a combination of the two is used.

When laying a set of points and crossings directly in the track, the exact position of the nose of crossing and the front end of the stock rail are marked in the existing track.

If possible, the position of the end of the stock rail should coincide with a joint so that cutting of rails is reduced to a minimum.

All material is collected at site and a very careful check is made to see that not even one small fitting is omitted. The closure rails are cut after careful measurement with a steel tape and bolt holes are drilled. Ballast is removed from the cribs. After stopping traffic, the appropriate rails and sleepers are removed, the bed is levelled, crossing sleepers are laid and the two switches and the crossing body inserted. After spacing the sleepers accurately, the straight line is spiked first with the stock and tongue rails in position and any kinks on the straight line removed by slewing. The opposite switch, namely, the one on the turnout side is then carefully gauged and fixed, the stock rail being given a slight bend with a jimcrow, a few inches ahead of the toe of the tongue rail. The crossing body is fixed and carefully gauged from the straight track. After fixing the rails on the straight track between the turnout switch and the crossing body and also the check rail on the straight, the straight track is opened for traffic. The lead and check rails on turnout side, the tie rods and the switch lever are fixed subsequently. The position of the turnout lead rail is fixed by offsets. The clearance at the toe of switch is carefully adjusted with tie rods. The switch lever is correctly positioned by keeping the lever in its central position, whilst the switches are at half clearance. The gauge is kept exact at the toe of switch and at the nose of crossing and may be kept slightly slack between these points over the turnout curve. If the points are to be interlocked, the interlocking connections are made and the turnout is ready for use after the necessary ballasting and packing. If the points and crossings are fabricated from heavier section rails than those on the track, the rails between the switches and the crossings body should be of heavier section. It is also advisable to lay a pair of heavier rails ahead of the switches and behind the heel of the crossing. If the track is subject to creep, the joints must be squared before laying a turnout. The track at either end of the turnout must also be adequately anchored, as creep alters the position of the switches and prevents manipulation of the points, particularly if they are interlocked.

If the turnout is laid by method (*b*), the sleepers are laid on unserviceable rails, the switches and crossing body placed in their correct positions and joined together with lead rails. The assembly is aligned, gauged, spiked and completed in all respects. The track

where the turnout is to be laid is opened out, all rails and sleepers and ballast upto the bottom of sleepers are removed and the assembled turnout slid into position. The slide rails are oiled, or greased, to facilitate movement and additional pieces added to enable the assembly to slide to its final position. The assembly may also be rolled into position by introducing lengths of pipes between the sleepers and supporting rails.

Complicated connections, involving diamonds of special dimensions, are best fabricated in a depot, *vide* method (*c*). The assembly is then divided into a number of units by disconnecting a few rail joints. These units are conveyed to the site in wagons and laid in position with the help of a crane.

If a turnout has to be taken off a curved track, the question of superelevation arises. This has been dealt with in para 1309.

818. Inspection of points and crossings

The inspection of points and crossings to be of any value, must be systematic and thorough. A casual glance, at irregular intervals, is unsatisfactory and is likely to lead to trouble. An inspection schedule should be prepared in which all points and crossings are listed, and an inspection time-table prepared. The inspection of each set of points and crossings should be carried out systematically and, to ensure this, some railways have special forms in which details have to be entered. Immediately after the inspection, the gang should rectify all defects noted, under the supervision of the Inspector or his assistant. The results of the work done should be noted on the inspection forms. Fig. 818 is a diagram showing the items to be inspected.

Most of the items given below are indicated in the diagram.

1. *Gauge:* This should be checked throughout, from a little in front of the toe of the switch to a short distance beyond the heel of the crossing, on both the straight and the turnout tracks. The switches should be turned for gauging the turnout track between the toe and heel of switch. Important points for gauging are the toe, centre and heel of switch and the nose and heel of crossing.

2. *Clearance:* These should be within the prescribed maximum and minimum and need checking particularly at the toe and heel of switch, between wings and the vee and at the check rails.

3. *Heel blocks:* In the loose heel type switches, the front bolts should be sufficiently loose to permit the necessary movement in the switch and the remaining bolts should be tight.

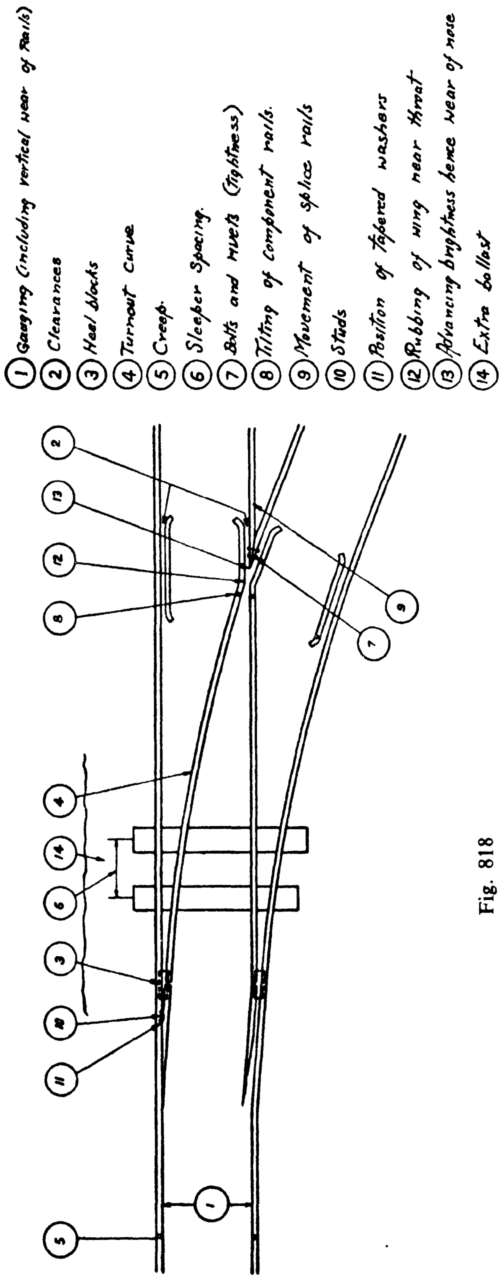

1 Gauging (including vertical wear of Rails)
2 Clearances
3 Heel blocks
4 Turnout Curve
5 Creep.
6 Sleeper Spacing.
7 Bolts and rivets (Tightness)
8 Tilting of component rails.
9 Movement of splice rails
10 Studs
11 Position of tapered washers
12 Rubbing of wing near throat
13 Advancing brightness hence wear of nose
14 Extra ballast

Fig. 818

4. *Alignment of turnout curve :* Should be checked by offsets from the straight track.

5. *Creep :* Stock rail joints must not be out of square.

6. *Sleeper spacing and packing :* Particular attention should be paid to the sleepers at the heel of switch.

7. *Bolts and fittings :* Should be very tight, with the exception of a few heel bolts (*vide* item 3).

8. *Tilting of rails :* There is a tendency to tilt on the turnout curve and this should be rectified.

9. *Movement of splice rail :* It should remain rigidly connected to the point rail.

10. *Studs and tapered washers :* Should be inspected.

11. *Wear of wing near the throat and advancing brightness of nose :* Both these indicate increasing wear and welding may be necessary.

12. *Ballast and drainage :* There should always be a sufficient quantity of good clean ballast; drainage should be adequate.

13. *Tongue rail :* Should have a snug fit with the stock rail and must have full bearing on the slide plates.

14. *Packing :* All sleepers should be thoroughly packed, particularly those under the heel of switch.

15. *Interlocking connections :* Should be clear of ballast and all connections should be tight.

16. *Switch lever box :* Should be firmly seated on the long sleepers.

17. *Manipulation :* The tongue rails should move easily.

819. Maintenance of points and crossings

All points and crossings should be attended to systematically and a programme of maintenance should be made out for each yard. Points and crossings in through and important tracks should be attended to more often than those in unimportant sidings. The sequence of operations may be as follows. Creep is removed first, clearances and gauge are rectified, sleepers squared and correctly spaced, all bolts are tightened, all sleepers are thoroughly packed and any remaining defects then attended to. The slide chairs need periodic lubrication.

Switch anchors in the form of Z-shaped ties are provided between the continuation of the tongue rail and a point behind the heel block of the stock rail. These prevent relative longitudinal movement between the tongue and stock rails.

Rail braces are sometimes used near crossings to distribute the thrust of the wheel flange over the two rails.

When the sleepers at the heel of switch are insufficiently packed, the toe of the tongue has a tendency to tilt up. This not only results in unnecessary wear of the tongue rail, but also introduces the possibilities of derailment. To avoid this, an angle, or tee or a flat bar may be attached to the foot of the tongue rails near the toe of switch and extended below the foot of the stock rail.

Attention to drainage of points and crossings well repays the trouble. As yards are usually on a level or flat grade and there are a number of parallel tracks, drainage is often not adequate and the ballast gets fouled. Screening of ballast under points and crossings improves the condition of the layout.

820. Welding of points and crossings

The maximum wear on points and crossings occurs at the toe of the tongue, and on the nose and wing rails of the crossing. When the toe of the tongue is worn, and this does not take very long under heavy traffic, the tongue has to be renewed. Deep grooves are formed on the wing rails and the metal on the nose gets worn. When this reaches a certain limit, the whole crossing has to be renewed, although other parts of the crossing may be in perfect condition. This wastage is overcome by depositing suitable metal on the worn parts by welding. Welding of tongue rails is being done to a limited extent, and welding of crossings is now an established practice in India. Crossings are welded and reconditioned either in a central depot or at site. In the former case, the crossing is removed from the track, transported to the depot, completely opened out and reassembled, and weld metal deposited on the worn parts. It is then relaid in the track, not necessarily in the place from which it was removed. For welding crossings at site, a portable welding plant is taken to the site and weld metal deposited in the interval between trains. Before welding, the crossing is thoroughly packed, all bolts are tightened and fittings and sleepers renewed where necessary. The gauge and clearances are corrected and if there is any vertical movement in the nose of the crossing, it is stopped with liners, so that no play occurs. All burrs and semi-detached strips of metal are chipped off from the running

edges. The areas to be welded are cleaned thoroughly, all grease, oil and dirt being removed, as presence of these results in bad welds. The lengths, to which weld metal is to be put on, is then ascertained by means of a straight edge and marked.

Weld metal is then deposited either by electric arc welding or by the oxy-acetylene process. In the electric arc process, a current is passed through the crossings and the electrode. The composition of the electrode is similar to that of the metal to be welded. The electrode has usually a covering of special material. When the electrode, after having been brought in contact with the crossing, is moved slightly apart, an arc is formed, possessing sufficient heat to melt the electrode as well as the rail, and the molten metal from the electrode is deposited and mixed with the metal of the rail. In the oxy-acetylene process, the intense heat required is produced by the oxy-acetylene flame. The runs of metal are kept parallel to the running edges and after each run, the slag from the electrode covering and the burnt metal are removed by chipping with a light hammer and by wire brushing. If this is not done, weak lines and planes occur in the weld metal, which consequently does not last long under the severe conditions to which it is subjected by the passage of wheels over it. The electrodes normally used for welding are of No. 6 and No. 8 standard wire gauge. After sufficient metal is deposited to bring the crossing upto full section, the weld metal is ground to the required shape. The cost of welding of a crossing at site has been found to be approximately 15% of the cost of a new crossing. The "life" of a welded crossing varies with the amount of traffic and also depends on the skill and care of the welder whilst depositing the weld metal. Assuming that a welded crossing has a life, only one-third that of a new crossing, the savings which result through welding are considerable.

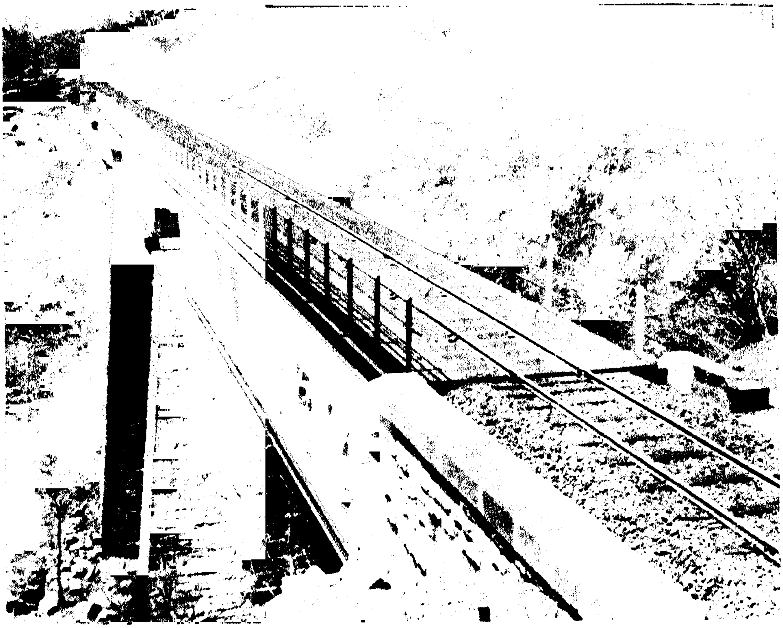
821. Miscellaneous

(*a*) In order to prevent vehicles on sidings from inadvertently fouling a main track, *derailing switches* or *derails* are fitted on siding tracks. A derailing switch is an ordinary point switch, fixed on one rail in the siding track, with the tongue facing the siding. The rail selected for fixing the switch is the one on the far side of the main track. The switch normally remains open and because of the break in the continuity of the rails, it derails any vehicle passing over it towards the main track.

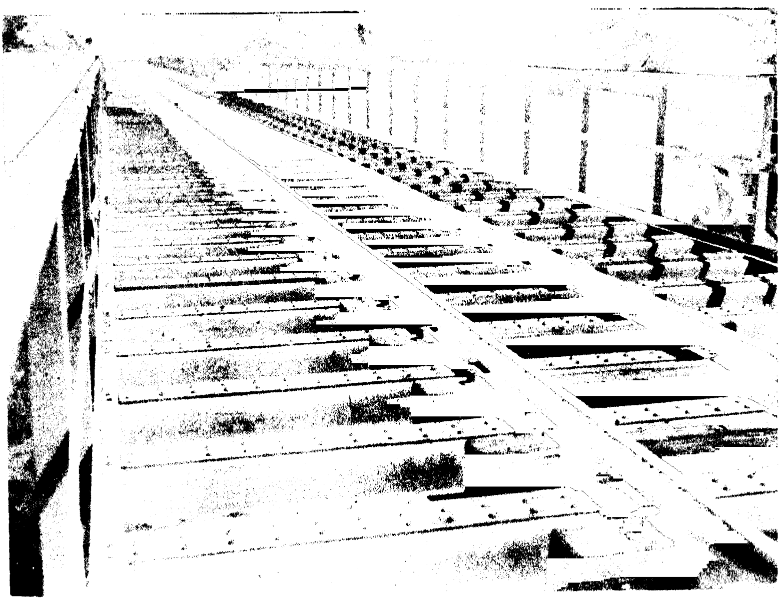
(*b*) As the toe of the tongue rail is the point from which diversion of all vehicles to one track or the other takes place, it is subject to considerable wear by the wheel flanges. To minimise

this wear, special hard steel wedge-shaped pieces, known as *point protectors*, are fixed just ahead of the toe of the tongue and guide the wheel flange slightly away from the toe.

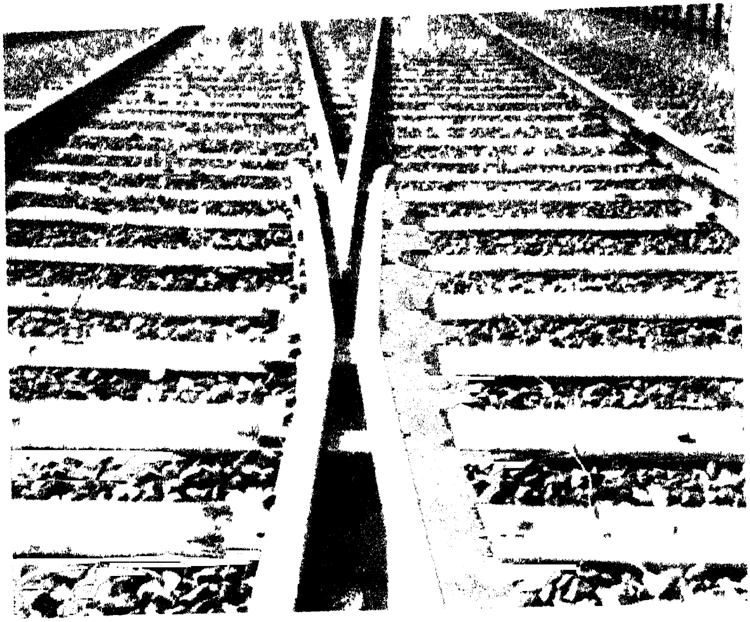
(*c*) In *switch diamonds*, the point rails of the obtuse crossings slide in the same way as tongue rails of switches. These point rails are suitably joined together with connecting rods. With this arrangement, flange spaces are avoided in the obtuse crossings. Switch diamonds are used where two tracks cross at a sharp angle.



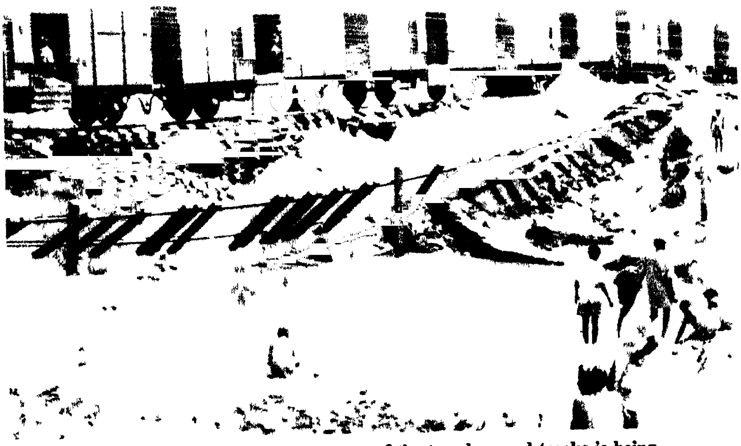
A viaduct for metre gauge track in hilly country



An unusual arrangement of wooden sleeper track on the trough deck of a bridge



A crossing showing nose, splice, wing and check rails



Repairs to flood damage. Only one of the two damaged tracks is being rehabilitated

Layout and Equipment of Yards

901. Considerations governing yard layouts and types of yards

STATION yards are located as close to a town or village as possible with due regard to future developments.

As land round station yards is in great demand, due to its proximity to transport facilities, ample area is usually retained at the time of railway construction, for future developments. An easy approach from the town or village to the passenger, as well as the goods, station is a great advantage. Yards are usually laid on a level, as gradients in the yard are not desirable. The gradient in difficult situation is limited to 1 in 400, whilst a maximum gradient of 1 in 1000 is recommended. If the gradient is steeper than 1 in 400, vehicles are liable to move on their own, due to wind, and this is positively dangerous. Location of yards in a place with upward inclines on either side should be avoided, as it is difficult to start trains on an upward incline and equally difficult to stop trains on a downward incline. Location at the summit of two gradients has distinct advantages. The layout of each yard depends on the extent of both passenger and goods traffic and on the type of traffic. Passenger traffic may be for long or short dis-

tances, or it may be seasonal. Goods traffic may be mostly inward or mostly outward; the commodities may be bulky or otherwise or traffic may be in one direction only.

Railway yards may be conveniently divided into four categories, namely, *passenger*, *goods*, *marshalling and locomotive yards*. The function of the *passenger yard* is to provide facilities for the movement of passengers and vehicles for passengers. A *goods yard* has to cater for the receipt, loading, unloading and delivery of goods and the movement of goods vehicles. Goods vehicles have to be sorted and marshalled so that they are placed in the order of the stations at which they are to be detached, and *marshalling yards* are required for this work. *Locomotive yards*, as the name implies, are required for servicing locomotives, namely, cleaning, loading coal, filling water, oiling, turning round, carrying out small repairs etc. Whilst passenger and goods yards are required at most of the train halting places, marshalling and locomotive yards are situated considerable distances apart.

902. Layout of wayside stations

The simplest type of station is a level piece of ground, where trains are stopped for passengers to enter or alight from trains. Such stations are called *flag stations* or *passenger halts*.

On sections of railways, with a single line of track, one of the functions of a station is to permit trains from opposite directions to pass one another. A *loop line* is therefore necessary. The loop may take ofl the main line, with a platform on either the main or the loop line. In Fig. 902*a* AB is the main line, CD is the loop; the platform is situated on the main line AB.

There are several variations of this layout, such as splitting the main line into two symmetrical loops, or positioning the platform along the loop CD, instead of the main line AB. All such variations have certain disadvantages, although they may be useful under a particular set of conditions. For instance, in the case of symmetrical loops the speed of through trains is severely reduced; in the case of a platform along a loop, later extensions of the yard are not very convenient.

In Fig. 902*a*, a train coming from direction A is admitted on main line AB. Another train from direction B is admitted on the loop line CD over the turnout BD.

On a double-line section, a crossover EB (Fig. 902*b*) is laid to enable trains to cross from one track to the other. At some double-line stations, it is necessary to permit a fast passenger train to overtake a slow goods train, travelling in the same direction. This

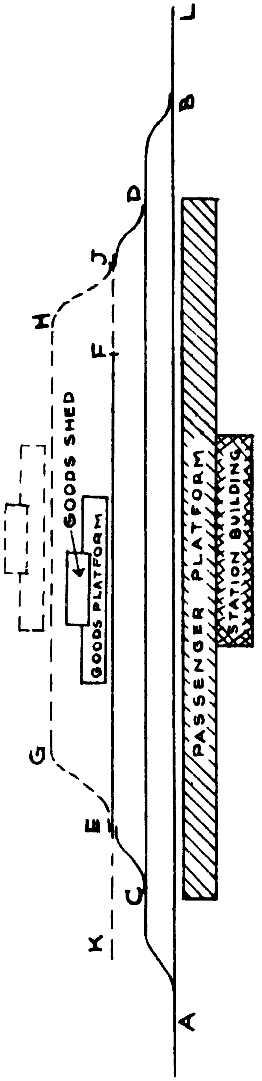


Fig. 902a

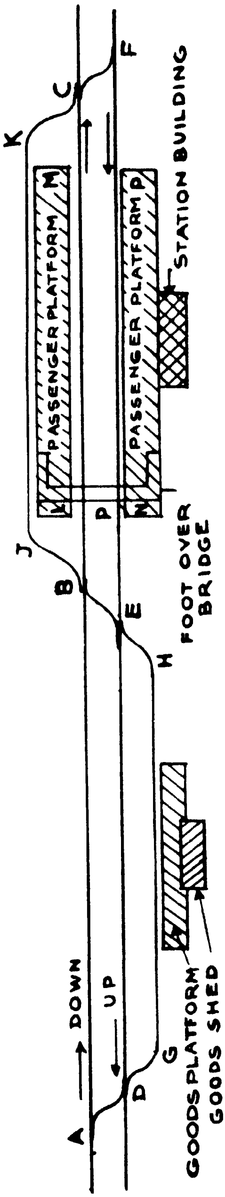


Fig. 902b

is done by introducing a loop BJKC, known as a *refuge line*. A slow goods, in the down direction, passes over the turnout BJ, whilst a slow goods, in the up direction, passes over the crossover FC and turnout CK, and subsequently resumes its journey over the turnout JB and crossover BE. Instead of the refuge loop, a *siding* BJK, namely, a line with a connection at one end only may be used. This would eliminate the turnout KC and the crossover CF, but considerable time would be wasted in taking the train to, and later bringing it out of, the refuge siding. For instance, a train in the up direction would have to travel beyond D, then back into the refuge siding, via crossover EB and turnout BJ. Whilst this is being done, all traffic, both on the up and down lines, would have to be stopped, to fulfil certain safety regulations (*vide* Chapter 23). Sometimes separate refuge sidings for each of the up and down lines are provided.

On the passenger platform, facilities are provided for passengers, in the form of waiting rooms or halls, refreshment rooms or stalls, water taps and lavatories, rooms for purchasing tickets and booking luggage, and overbridges or subways for crossing tracks. Rooms are also provided for the station staff to receive and despatch train signals and telegrams, carry out clerical duties, store parcels, lamps etc. The number and size of rooms and halls depend on the amount of traffic.

So far only facilities for movements of or in connection with, passenger trains have been dealt with. Goods facilities are also provided as shown in Figs. 902*a* and 902*b*. For stations on single lines, a dead end siding EF, with a goods platform and shed, are adequate for a small station. This however entails movement of wagons by hand shunting when wagons have to be attached to, or detached from, a train travelling in the direction A to B. The wagons have to be hand shunted from siding EF to loop CD, to enable the engine at end B to pick them up. This is avoided, if the siding EF is extended to form loop EFJD. For stations on double line the loop DGHE, shown in Fig. 902*b*, is suitable.

If, due to increased traffic, an additional track is required, this can be easily provided as shown dotted in Fig. 902*a*. An additional loop EJ is obtained by providing a new goods siding EGH or loop EGHJ, and moving the goods platform and shed.

As a safety precaution, all sidings and shunting lines are isolated from the running lines. *Running lines* are tracks used for receiving or despatching trains, or over which trains run through, without stopping. The object is to prevent any vehicle on the siding or shunting line, inadvertently running into trains. *Isolation* is provided by means of *trap points* or *derailing switches* at E and J

(Fig. 902*a*). These consist of switches which normally remain open. Any vehicle moving, say from EJ towards JD, is derailed at the trap point at J. The derailing switch is closed when vehicles have to be put in or taken out of the siding. Instead of the derailing switch, a short siding EK, known as *trap siding*, may be provided. Yet another method of isolation is the placing of an obstruction, called a *derail* (Fig. 902*c*), on the rail at E or J, to derail vehicles moving in an unauthorised direction. A primitive type of derail consists of a block of wood placed on the rail and suitably held in place; it is called a *Scotch block.*

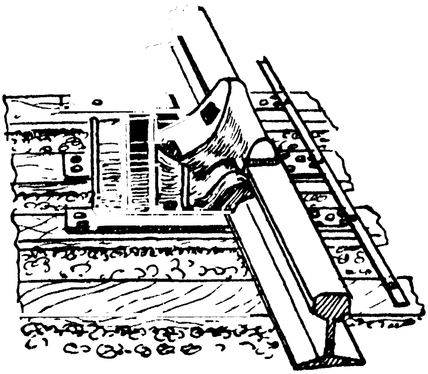


Fig. 902*c*

With the trap points E and J open, shunting can still be performed in the goods yard, if the siding EK is sufficiently long. When thus used, the siding EK is known as a *shunting neck*. When, in hilly country, the gradient near a station is so steep that danger is apprehended from vehicles running back, a *catch siding*, with point normally set for the siding, is installed outside the station yard.

Sidings are often laid from yards to industrial concerns, mines, collieries, etc. When the siding is laid at the expense of and is entirely maintained by the concern, it is known as a *private siding*. If the track is laid at the expense of the railway, the formation is built by the concern and maintenance of track is carried out by the railway, the siding is called an *assisted siding*.

903. Junctions and terminals

Where a branch line joins a main line, special arrangements are made at the junction station for the interchange of traffic between the main and the branch lines. Such junctions may occur between a single-line branch and a single or a double-line main track, or between double-line branch and main tracks. Fig. 903*a* illustrates a junction between single lines. ABC is the main line and DEF a branch line. Interchange of passengers takes place across the platform GH. The loop ELF is provided to enable the engine at end F to run round to E, for hauling the train back in the direction ED, or to enable the engine to be released for servicing. The crossover AE gives a physical connection between the main and the branch lines.

A junction between a single-line branch and a double-line main track is illustrated in the same figure by broken lines. ABC and MN are the two main tracks and JK is an additional platform, access to which is obtained from the branch line platform over the bridge P.

Fig. 903*b* illustrates a junction between double-line branch and main tracks. The crossover CG enables a train, received from

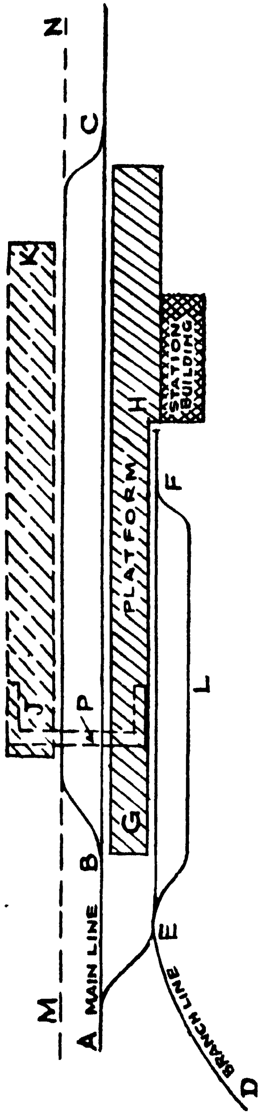


Fig. 903*a*

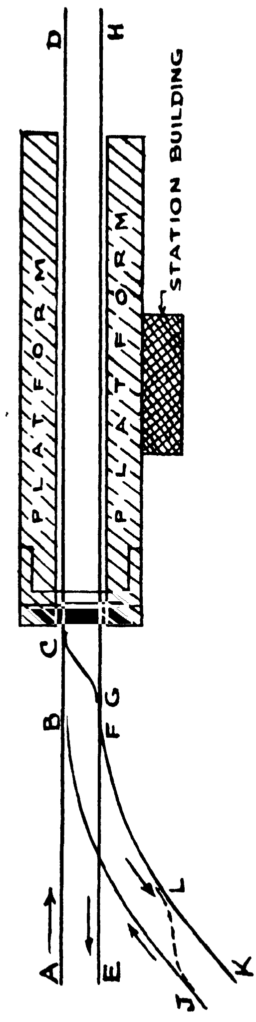


Fig. 903*b*

line JB on the platform line CD, to proceed on its return journey along FLK. A similar arrangement for a junction between single-line branch and double-line main is also possible. It is obtained by eliminating track LK (Fig. 903*b*) and introducing a turnout LJ.

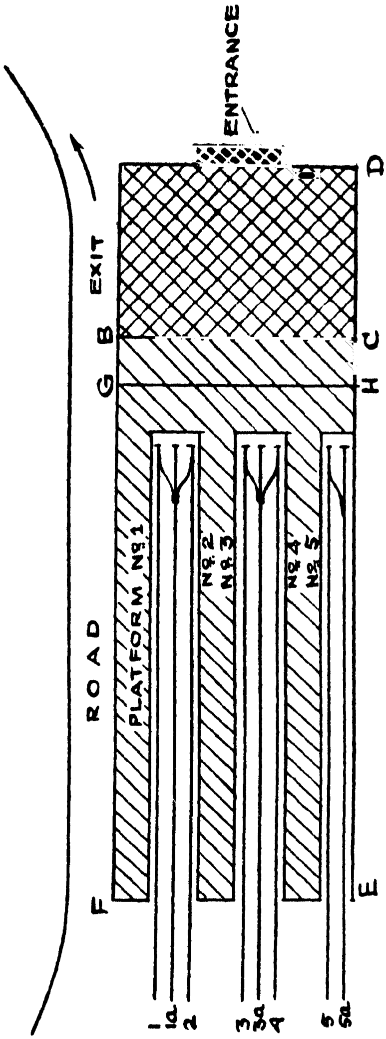


Fig. 903*c*

Figs. 902*a*, 902*b*, 903*a*, and 903*b* illustrate very simple layouts. Important stations are provided with elaborate layouts, depending on the requirements and local conditions. If the suburban service at a large town is heavy, special tracks and platforms are provided exclusively for the suburban trains. At junctions, the vehicles of a train terminating at the junction have to be cleaned, stabled and repaired, and facilities for such work have to be provided.

For heavy goods traffic, a large number of goods sidings and several sheds are required and in such cases, each shed deals with traffic in a particular direction or of a particular type.

In Fig. 902*b* platform LM is known as an *island platform*, as it is surrounded by tracks and access for passengers is by an *overbridge* P. *Subways* are sometimes provided instead of overbridges.

Track EF (Fig. 903*a*) is called a *dock line* and the adjacent platform is known as a *dock platform*.

Fig. 902*a* may be taken as an illustration of a terminal station, namely, a station at which a railway or one of its branches terminates. The line AB may terminate at L. Facilities for servicing engines and vehicles are necessary, but these are not shown in the figure. A terminal station with heavy traffic at an important town is shown in Fig. 903*c*. The area BCD contains various facilities for passengers and includes a large concourse or hall for the use of passengers. GH is a barrier, at which tickets and luggage are checked. Five platform faces are provided, of which No. 1 platform is for trains arriving at the terminus. A road is provided alongside, to enable passengers to proceed immediately by road vehicles. Platforms 4 and 5 may be reserved for suburban service and platforms 2 and 3 may be used chiefly for long-distance departing trains. In between the platform lines, additional tracks, 1*a*, 3*a*, and 5*a*, with crossovers to platform lines are provided, to enable engines of trains, which have arrived, to be released. These intermediate tracks are sometimes omitted and the engine is released when the whole train is backed on to servicing lines. Facilities for servicing engines and for marshalling and servicing vehicles are not shown.

904. Marshalling yards

The usual method of working of goods trains is to pick up or detach wagons, either loaded or empty, at various wayside stations as required.

Such goods trains are known as *Shunting* or *Pick-up goods* trains. Goods trains are run between distributing centres, a reasonable distance apart, say 50 to 150 miles, with several intermediate stations. When all the wagons in a goods train, starting at a distributing centre, are meant for the next distributing centre or beyond, the goods train runs direct between the two distributing centres and is known as a *through goods* train. Sorting of wagons, according to traffic requirements, is not done at wayside stations, but is concentrated at the distributing centres. For this purpose a marshalling yard with an elaborate set of sidings is provided. Goods trains are marshalled, so that wagons are placed in the order of the stations at which they are to be detached. As wagons may be received by goods trains from several directions and stations, a considerable amount of sorting of wagons and reforming of trains is necessary in a marshalling yard. This yard also serves as a distributing centre for empty wagons, required at various stations.

There are three types of marshalling yards : (*a*) *flat*, (*b*) *gravitation*, and (*c*) *hump yards*. In the *flat yard*, all movements of wagons

are carried out with the help of engines. Such yards are wasteful in the use of engines and are only justified where space is limited, as the two other types of yards require a greater area. In the *gravitation yard*, the tracks are laid on such a gradient that wagons move on their own accord and the movements are controlled with the wagon brakes. Gravitation yards, however, require the formation to be at a certain slope and the topography of the country may not easily lend itself to this. A *hump yard* is one in which the wagons are pushed up a "*summit*" by an engine and gravitate down the opposite slope into various sidings. Marshalling yards are designed so that wagons move in one direction only, as reverse movements entail a good deal of extra work and delay. A well-laid out marshalling yard is divided into three sets of sidings, namely, (*a*) *reception lines*, (*b*) *sorting sidings* and (*c*) *departure lines* (Fig. 904). Separate sets of sidings are provided for marshalling of wagons in the up and in the down directions. Goods trains are received on the reception sidings and await their turn for shunting. The train engine is detached and sent for servicing and the wagons are examined for any defects whilst the train is waiting. The train is then pushed over the hump with the help of a shunting engine and the wagons roll into various sorting sidings. They are then collected from the various sorting sidings to form complete trains in the departure lines. The complete train proceeds on its journey as soon as an engine is attached and the main line is clear to receive the train from the yard. The trains in the departure lines are formed in station order, namely, wagons which are destined for the first station are kept next to the engine, followed by wagons for the second station and so on. The reception and departure lines are of lengths sufficient to accommodate the longest goods trains running in the section served by the marshalling yard. The number of sidings in the reception and departure lines depends on the number of goods trains to be marshalled, the time taken for marshalling each train, the time required for inspecting wagons for possible defects and on the density of traffic on the main line. The departure lines are sometimes omitted if there is a large time interval between the departure of successive goods trains and if the main line is not too busy. The reception and departure sidings are gathered together at both the ends. They are usually in the form of grids as a grid gives the most economical layout.

The sorting sidings are situated between reception and departure lines and their number depends on the number of destinations or groups of stations, to which wagons have to be despatched. The sorting or marshalling lines are also gathered together at both ends and are usually in the form of a "balloon." The *hump* is

located at the entrance to the sidings and a grade of about 1 in 50 for a very short length, then 1 in 150, followed by a level stretch are provided. The grade to the hump, at the pushing end, is usually 1 in 150.

The sorting sidings may be depressed at the centre of their lengths with advantage, the ends being given suitable gradients which facilitate movement of vehicles without undue acceleration. Steeper gradients are required on the outer sidings to compensate for curve resistance.

Individual wagons or groups of wagons are uncoupled and the train pushed up the hump. The first wagon or group of wagons roll into the appropriate sidings. The next wagon or group of wagons roll into another siding; these operations are repeated. The stopping of wagons rolling down a hump, at the exact place required, presents a difficulty in hump and gravitation working. The usual method is for men to run along the wagons and apply the wagon brakes. Automatic braking is done in some countries by fixing blocks or bars, known as *retarders*, on either side of the rails. These retarders are operated electrically or electro-pneumatically, so that they press against the sides of wheels and bring the wagons to a stop. In India, skids placed on rails have been tried. The *skid* is dragged by a rolling wagon and the friction thus caused, helps to stop the progress of the wagon. Tracks are provided in marshalling yards for the release of train engines and stabling of brakevans and cattle wagons, whilst shunting is being carried out. One or more sidings for defective wagons, with necessary repair facilities and a tranship platform, for removing goods from a defective wagon and reloading in another wagon, are also provided. The engine shed is located as near to the reception and departure lines as possible and the most suitable position for the yard office is near the hump. The yard is usually so laid out that future extensions may be made without difficulty. The location of both the up and the down marshalling yards on one side of the main line is considered the best arrangement for working the yard.

Electronic equipment has been introduced in U.S.A. for working marshalling yards. A radar-operated speed indicator located at the foot of the hump, measures the speed of the descending wagon and the distance it must travel and transmits the information to an electronic calculator in the control cabin. This calculator operates electro-pneumatic retarders ahead of the points in such a way that wagons roll through the points and couple up with the preceding wagon at three miles per hour.

The destinations of wagons in the train are teletyped in advance to the shunting master who relays it to the control cabin. The rolling of wagons into the correct marshalling track is done by push button control from the cabin.

905. Loco yards

Facilities have to be provided for stabling and servicing of locomotives. These facilities are grouped conveniently in loco yards. The loco yard contains a number of tracks leading to the engine shed, ashpits, inspection pits, repair pits, turntable, coaling site, repair shed etc. (Fig. 904). Servicing of a steam engine includes the raking out of ashes from the fire box, blowing down steam, loading coal, filling water, oiling the mechanism, periodically washing out the boiler, carrying out small repairs and turning the engine round if necessary.

The tracks in a loco yard are so arranged that the servicing of the engine may be carried out in the proper sequence, without unnecessary shunting or without interfering with the movements of other vehicles. One entry line from the traffic yard is usually provided, with a subsidiary line to act as an emergency entrance, in case the main entry is blocked, due to derailment, etc. The number and length of sidings are normally sufficient to accommodate the maximum number of engines likely to be in the yard at the same time. A considerable area is necessary for stacking coal and for dumping ashes for subsequent removal. Sidings are provided along the coal stacking ground and in the ash dumping area and are located in such a way, that these sidings are accessible to vehicles from the traffic yard, without their having to pass over the engine shed lines. Sufficient space is also often left in the yard for future expansion.

906. Engine sheds

The purpose of an *engine shed* is to enable engines to be stabled and to be maintained in a serviceable condition. There are two main types of sheds, (1) with parallel tracks and a rectangular structure (*vide* Fig. 904) and (2) with radiating tracks and a circular or polygonal structure, known as a *round house* (Fig. 906).

The rectangular shed is common in India, but round houses also exist. Round houses are favoured in America. Round houses are not only very economical in space but also provide better facilities for maintenance and repairs of engines. Moreover, a great deal of shunting operations is avoided in placing and removal of

engines. They however suffer from the disadvantage that if the turntable, over which all engines must pass to and from the shed, goes out of order, the engines in the shed cannot be taken out. In the rectangular shed, the parallel tracks are gathered together at one end, and often at both ends, enabling engines to enter or leave the shed at either end.

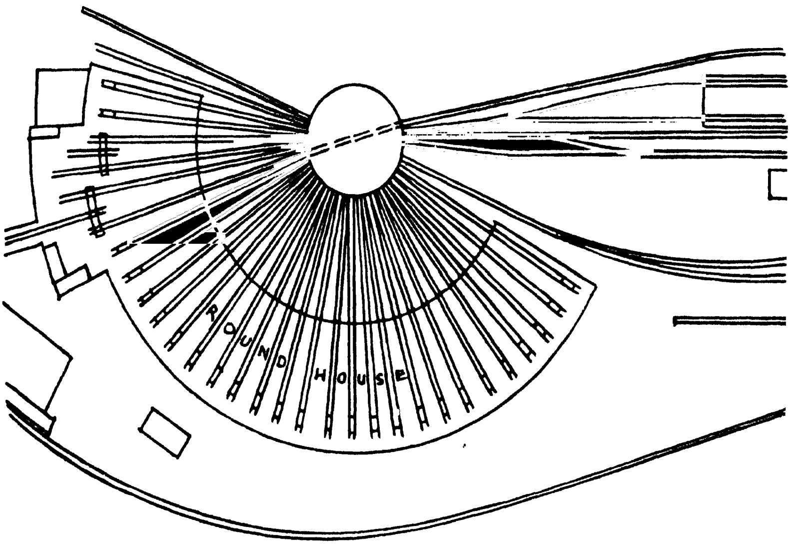


Fig. 906

Modern engine sheds consist of steel or reinforced concrete frames with north-light (saw-tooth) roof, with sides and roofing of corrugated iron or corrugated asbestos-cement sheets.

Examination pits are provided under the tracks in the shed so that the engine mechanism may be inspected from below. Hydrants for supplying hot water under pressure, and for periodic washing out of boilers of engines, are provided at close intervals between the tracks in the shed.

A small repair shop, a storeroom containing various lubricating oils, small spare parts of engines and other stores, and an office, are incorporated in the shed. A *drop pit*, in which engine wheels can be lowered for examination, repairs or renewals, is either provided in the shed, or is housed in a small adjoining shed. Special arrangements, consisting of cowls or special openings on the shed roof, are provided for removing the smoke from engines and prevent it from spreading in the shed.

907. Equipment in loco yards

(*a*) *Ashpits, ashpans, examination pits, drop pits.*—

Ashpits for raking out ashes from engines consist of long pits about 2′-6″ to 4′-0″ deep (Fig. 907*a*). The pits have two masonry or concrete walls, surmounted by longitudinal beams, either of timber, concrete or steel, on which the track rails are fixed. The beams are held to the walls with bolts. The pits have masonry or concrete floors which are sloped to the centre or to one side to form a drain. Water is removed from the pit through a sump and drain. Ashpits are made a little longer than the longest engines in use on the section.

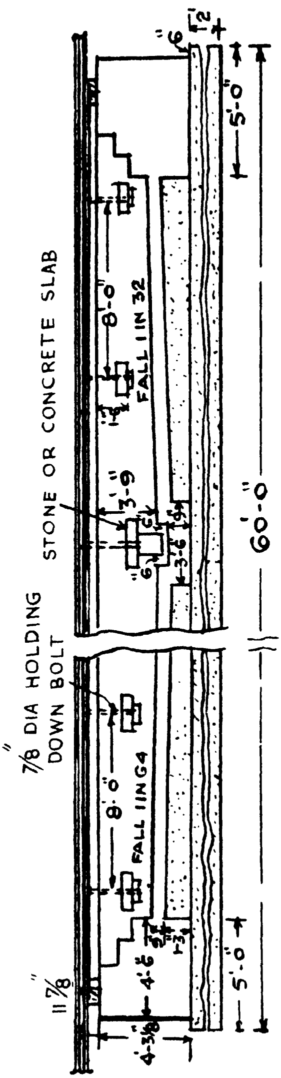


Fig. 907*a*

As there are no cross connections between the longitudinal beams supporting the rails, the gauge should be checked occasionally, particularly on old timbers. As hot ashes are liable to burn the timber beams, it is advisable to protect the timbers with steel sheets. Ashpits are also provided on the platform lines at certain stations to rake out ashes from the engines whilst they are filled with water.

Ashpans consist of U-shaped precast reinforced concrete sections placed side by side and supporting the rails on their top edges. These sections form a shallow pit which is used for the same purpose as an ashpit. Ashpans are usually found at engine watering stations.

Examination pits are similar to ashpits but are used for examining the engine mechanism from underneath. These pits are usually longer than ashpits.

Drop pits enable wheels to be removed from an engine for examination, repairs or renewals. The pit is constructed at right angles to the track and a mobile hydraulic jack is installed to enable the wheels and axles to be removed.

(*b*) *Turntables.*—A turntable is a device for changing the direction of an engine and consists of a platform with a track on a pair of girders. The girders are suitably braced together and are supported on or suspended from a central pivot (Fig. 907*b*). The turntable is installed in a circular pit and two or more tracks radiate from the edge of the pit. The track on the turntable is kept at the same level as the tracks radiating from the edge of the pit. When an engine is to be turned, the turntable is revolved on the pivot until the track on it comes in line with the track on which the engine is standing. Further movement of the turntable is prevented by locking bolts and the engine moves on to the turntable. The locking bolt is removed and the turntable, with the engine on it, is rotated by power or manually. When engines were not very heavy, the load was balanced on the pivot, but the engine had to be so positioned on the turntable that its centre of gravity fell directly on the pivot. Later, a three-point support was introduced. In such turntables the load is carried on the central pivot and at the two ends of the turntable girders, on flangeless wheels A fixed to the girders. These flangeless wheels travel on a rail B fixed in the pit along its circumference. This

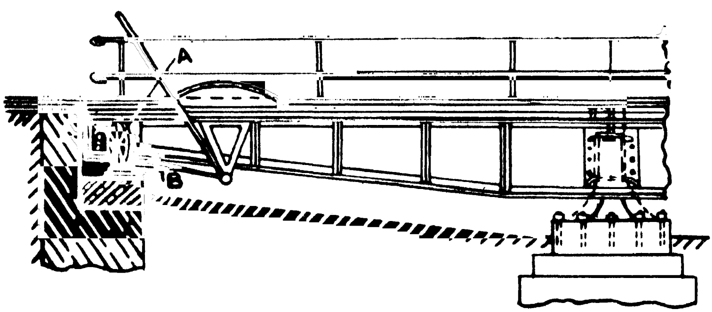


Fig. 907*b*

type is common in India. With still heavier loads, the non-continuous type of turntable has been introduced. In this type, the turntable girders instead of being rigid are provided with joints at the centre so that the two halves act independently for supporting the load but rotate as one unit. The central bearing may be of the disc type for light loads and of the roller type for heavier loads.

The bottom of the pit is sloped towards a point near the centre where a sump and drain are provided to carry away rain water. Turntables have to be long enough to accommodate the longest engines. A length of 65′ is common in India and there are several turntables of 85′ length. In America 100′ turntables are common and lengths of 130′ are also used.

A turntable is liable to corrosion due to the presence of water and steam from engines, and needs periodical painting. The circle or race rail has also to be kept in perfect level. As this rail is often supported on short blocks of timber the adjustment is not difficult.

(*c*) *Triangles.*—For turning an engine, triangles are also used, particularly at terminals of short branch lines, where the installation of a turntable may not be justified. A triangle (Fig. 907*e*), as the name implies, consists of three short lengths of tracks in the form of a triangle, two of the tracks AB and BC being laid on curves (sometimes all three are curved). The connections at A and C consist of turnouts and that at B is a symmetrical split. A short dead end siding BD is required to accommodate the length of an engine. An engine at A, with its front towards C, moving from A to C, C to D and D to A will have its front facing away from C, on its return to A. In order to set out a triangle, distances EP and FG are required. The radius of the symmetrical split is taken as the radius of the two curves LJ and SM.

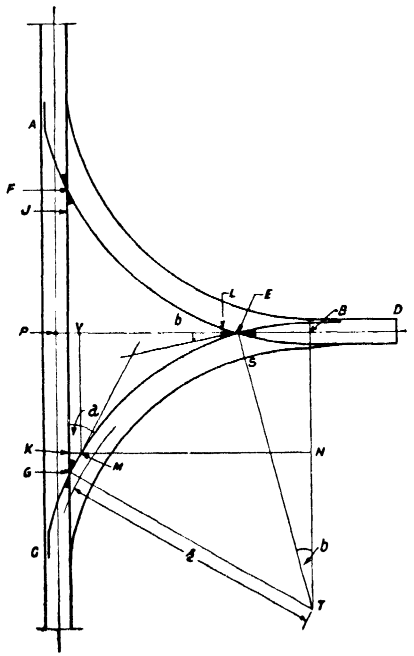


Fig. 907*e*

$$EP = PV + VB - EB \text{ and}$$

$$FG = 2KG + 2PK.$$

KG is equal to the distance from the theoretical nose to the heel of crossing for the turnout at G.

$$VB = MN = \left(r + \frac{g}{2}\right) \cos a \text{ where } g = \text{gauge}$$

$$EB = ET \sin b = \left(r + \frac{g}{2}\right) \sin b$$

$$PK = BT - NT = r - \left(r + \frac{g}{2}\right) \sin a$$

$$PV = \frac{g}{2} + \text{spread of heel at crossing G.}$$

From these the distances PE and FG are obtained.

(*d*) *Coaling plants.*—Tenders of engines have to be filled with large quantities of coal. The most primitive, but sometimes the cheapest way in India, is for men to carry baskets full of coal up a sloping plank to the top of the tender. An improvement in this method is to build a stage, level with the top of the engine tender and adjoining the track. This method is used for coaling engines of through passenger trains at intermediate stations. A large number of baskets full of coal are kept ready loaded on the staging. On the arrival of the train, the engine pulls up alongside the staging and the baskets are rapidly emptied in the tender. Portable mechanical devices are also used in India. These are : (1) A mobile steam crane with clam shell buckets at the end of the jib. The bucket grabs the coal from a stack and deposits it in the tender. (2) A coal conveyor which consists of a moving belt mounted on a frame at an angle to the horizontal. Coal is thrown at ground level into a hopper and the belt, which is worked by electricity, conveys it to the top of the tender. The conveyor is provided with wheels and can be moved along the coal stacking ground. (3) In elevated coal bunkers the coal is elevated by a bucket conveyor to an elevated bunker, from which it falls through chutes to the tender of the engine below. This type is used at some stations in India. (4) Coal hoists, in which the wagon containing coal is raised to a higher level by power, and emptied by tilting the whole wagon. Coal from the tilted wagon falls into hoppers, from which it reaches the engine tender through chutes. The wagon is firmly held by a mechanical device while it is tilted. (*e*) Elevated trestle stagings are also used in America and elsewhere. The coal wagons are pushed up a track on the top of the trestles and emptied into hoppers, from which tenders are filled through chutes.

Coal, which is stored on the ground in all loco yards, is built up into stacks. It is advisable to floor the stacking ground to prevent earth from being scraped up with the coal.

908. Equipment in station yards

(*a*) *Platforms.*—The length of passenger platforms depends on the length of the longest passenger trains running on the section. For a full length B.G. train, a length of 950′ to 1,000′ is desirable. The edge of the passenger platform is kept 5′-6″ from the centre of the nearest track for B.G., 4′-5″ for M.G. and 4′-0″ for N.G. When platforms are situated on curves, extra clearances are given as explained in para 1507. Three types of platforms are common on the B.G., namely, the *rail level*, the *low level*, which is upto 1′-6″ above rail level and the *high level* which is 2′-6″ to 2′-9″ above rail level. On M.G., platforms at rail level and 1′ to 1′-4″ above rail level are used. N.G. platforms are at rail level or from 9″ to 1′-4″ above rail level. With platforms higher than rail level, ramps at a slope of 1 in 6 are provided at each end. The width of a platform varies, but should normally be not less than 12′. Buildings are not allowed within 12′ of the platform edge for all gauges in India. Platform surfaces may consist of rammed moorum, water-bound macadam, flagstones, set stones, concrete or bitumen.

The platform may be without a cover, or the whole, or part of the platform may be roofed over.

Goods platforms are usually made of such a height as to be level with the wagon floors. This facilitates handling of goods. The normal height for B.G. is 3′-6″ above rail level, for M.G. 2′-3″ and for N.G. 2′-0″.

(*b*) *Buffer stops, end loading ramps, trap points, trap sidings, derails, fouling marks.*—Where sidings terminate, some form of stop is fixed to prevent vehicles moving beyond the end of the rails. These invariably consist of a horizontal buffing beam A of timber, or of a couple of rail pieces, (Fig. 908) and at the level of the buffers on vehicles. The beam is held in position by vertical posts BC made of rails or I sections and fixed to the track. The beam and posts are strengthened by struts DE and ties EF. For vehicles with a

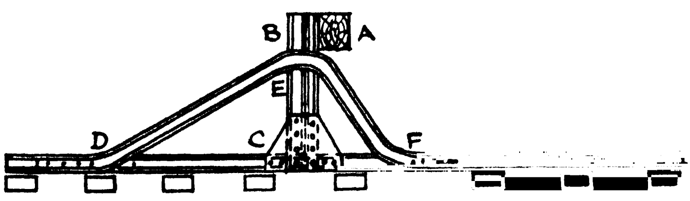


Fig. 908

central buffer, the beam A is replaced by a central block, and the verticals BC are made sloping from the rails at C to the central

block at B. Very useful buffer stops are also made from wooden sleepers removed from the track. The sleepers are placed vertically, side by side, to form a box, which is filled with earth. The sleepers are held together near the top by a suitable band of flat iron or old rails. The height of the sleepers is gradually reduced from a level, a little above the buffing beam at the front, to almost rail level at the back end of stop. The sloping surface of the earth filling may be turfed.

For loading road vehicles into wagons, an *end loading ramp* is necessary. This is merely a strip of platform at the end of a siding built to the height of the wagon floor and gently sloped to road level. An ordinary buffer stop is fixed in front of this platform and the space between the wagon floor and the platform is spanned by hinged plates. The buffer stop must be kept a little away from the platform masonry, otherwise the masonry is liable to damage if a wagon inadvertently bumps into the buffer stop. The height, above rail level, of end loading ramps is 4′-3″ for B.G. and 2′-10″ for M.G.

At terminal stations hydraulic buffers are installed at the ends of platform tracks as a safety measure.

Trap points, trap sidings and derails have been described in para 821.

When two tracks converge, side collisions are possible between vehicles standing on the turnout portion of the track and those moving over the adjoining track. To guard against this possibility *fouling marks* are placed between each pair of tracks where they converge. Fouling marks may be made of unserviceable sleepers, stone or concrete slabs, painted or whitewashed to make them prominent. They are fixed in the ground, at right angles to the tracks, at points between converging tracks beyond which sufficient side clearance is available between wagons. The minimum distance between centres of tracks where fouling marks are fixed, are 14′ for B.G., 12′-6″ for M.G., and 12′ for N.G.

(*c*) *Cranes, weighbridges, loading gauges.—Cranes* are used for loading and unloading bulky materials such as logs from wagons. They are of four different types. The most common type is the *fixed jib* type, located at a convenient spot on goods platform. The most useful type is the *mobile crane,* mounted on a vehicle and used anywhere in the yard. The third type, known as a *gantry,* consists of two parallel beams supported on vertical posts. Hoisting machinery is installed on a platform which travels on the parallel beams. Wagons or road vehicles are brought under the gantry for loading or unloading. The fourth type, called a *Goliath,* is a variation of

the gantry and consists of a frame, made of two posts and a beam, with the lifting tackle on the beam. The frame travels on a track on the ground.

Weighbridges are provided where whole wagon loads are required to be weighed. They consist of a short length of track on a platform supported on beams. The beams are located in a pit under the track and a wagon is brought on to the platform for weighment, the mechanism is so adjusted that the beams rest on knife edges attached to levers. The weight is indicated by a pointer, on a graduated disc, fixed in an adjoining structure. Weighbridges must not be located in a through track and vehicles should pass over it at a very slow speed as the mechanism is otherwise likely to be damaged.

In order to ensure that bulky goods loaded in wagons do not project beyond specified dimensions, to prevent their fouling any structure on their journey, *loading gauges* are provided. A loading gauge consists of a pair of posts, a specified distance apart with a cross arm at a specified height above rail level.

Similar gauges are also fixed at level crossings on electrified sections with overhead wires, to prevent road vehicles fouling these electric wires.

(*d*) *Carriage washing platforms and examination pits.*—High narrow *washing platforms* are provided between tracks, to enable passenger carriages to be swept and washed. Hydrants are located at short intervals on the platform, to which short flexible pipes are attached and water is sprayed on the carriages.

Examination pits, for facilitating the examination and repairs of bogies and brake gear of carriages, are provided usually on or near washing platform tracks. These pits are similar to the pits described in para 907*a* but are much longer.

909. Water supply at stations

A considerable quantity of water is required at a station for passengers at the station, for the use of the staff, for filling water in carriages and engines, for hydrants for fire-fighting, for washing out engines and for other sundry purposes. At small wayside stations, only the supply to passengers and to staff may have to be arranged and this is done from small wells, the water being filled manually and kept in suitable vessels in a convenient place. When a large quantity of water has to be arranged, such as at large passenger or goods stations, at stations with locomotive yards and

at intermediate stations, where engines have to be filled with water, steam or electric pumps are installed. Water is pumped to overhead tanks and distributed through cast iron, wrought iron, steel or asbestos-cement pipes. The source of supply, which may be shallow wells or tube-wells, reservoirs, rivers, or springs, need not be considered here.

Overhead tanks (Fig. 909*a*) varying in height normally from about 15′ to 50′ are usually made out of cast iron or steel plates suitably braced and supported on steel stagings or on masonry towers. Tanks made of timber are used in America and those of reinforced concrete with pillars of the same material are increasingly used in various countries including India. The shape of overhead tanks in India is mostly rectangular whilst circular tanks are favoured in America. The bottom of these circular tanks are made flat, conical or hemispherical. Overhead tanks are provided with supply and delivery pipes. A *ball valve* prevents waste by closing the pipe when the tank is full. This is essential when the source of supply and the pump are situated a great distance from the overhead tank. A *non-return valve* on the tank enables one pipe to be used both for supply and delivery purposes. A *reflux valve* is installed to prevent damage to the pump by the pressure of water in the pipe line. The height of the tank is governed by the water pressure required to overcome friction through pipes. *Scour* and *air valves* are located at the lowest point and at the summit respectively of pipe lines. If the pipe line is long and rises and falls with the ground, scour and air valves are located at all

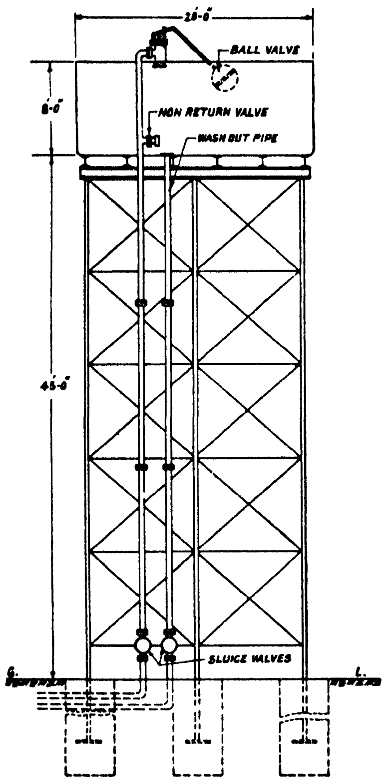


Fig. 909*a*

the lowest and the highest points respectively. The scour valve is used for scouring out the pipe and the air valve for the escape of air trapped at summits of the pipe line.

The diameter of the pipes depends on the quantity of water required. The velocity of water in pipes is greatly reduced due to friction and the relation between the quantity of water required, the pressure available (depending on height of overhead tank) and the diameter of the pipe have to be carefully considered. Diameters ranging from 3″ to 9″ are usual for the main supply pipe. The delivery pipe to water columns is usually not less than 8″ in diameter, whilst delivery to other points is through pipes of diameters 3″ to ½″.

Water is supplied to engines through *water columns* (Fig. 909*b*). A water column consists of a vertical pipe with a swivelling arm of either a horizontal or swan neck shape. A valve is fixed in the water column for opening or closing the supply. The wheel for manipulating the valve is fixed either near the ground or near the spout. A light funnel is provided to enable water to be directed to the opening in the engine tender, without splashing. A perforated disc in the spout, which prevents splashing is now replacing these funnels. In Britain, to avoid detention to trains whilst water is being filled in engines, long shallow troughs are located under the track and water is scooped up by a special apparatus on the engine travelling over the trough at speed.

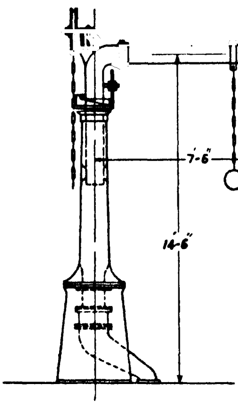


Fig. 909*b*

Fig. 909*c* shows a typical layout of pipe lines, overhead tanks and water column. Arrangements for draining surplus water have also to be made. Open drains, and earthenware or concrete pipes are normally provided. Sumps are necessary at various places for cleaning and other purposes.

Water, which contains salts of calcium and magnesium, are harmful to engines as calcium salts form heavy deposits in boilers and magnesium salts corrode the metal of boilers. *Water treatment plants* are therefore installed at some stations to remove these salts. Lime and soda ash when mixed with water deposit the objectionable calcium and magnesium. Treated water is not normally fit for human consumption and this supply has, therefore, to be isolated.

If water for human consumption is not pure, it has to be filtered and sterilised. Separate treatment plants have sometimes to be installed for this purpose.

In order to ascertain the approximate quantity of water available at any point in a pipe line, the following formula may be used.

Quantity = area of pipe × velocity of water = $.78d^2v$ where d = diameter of pipe in feet and v = velocity of water in feet per second. v is obtained from the formula

$$v = \cdot 78 \sqrt{\frac{d}{4} + \frac{h}{l}}$$

where h = height of overhead tank, and

l = distance of overhead tank from the point considered on the pipe line.

The quantity obtained is in cubic feet per second.

As the quantity is normally specified in gallons per minute, the figure obtained is multiplied by $6.24 \times 60 = 374$.

Overhead tanks have to be cleaned at intervals of a few weeks, to remove silt and other foreign matter. The tanks, if made of steel, require to be scraped and painted periodically to avoid corrosion and subsequent failure through leakage.

Pipe joints are also liable to develop leaks. If a leaking joint is found on pipes with flanges joined together with bolts, the flange faces should be coated with red lead, or a new gasket or flexible washer should be inserted between the flanges, and the bolts tightened up. If the pipes are screwed together, a little white lead and some yarn should be wrapped round the threads before re-screwing. If the joints are of the spigot and socket type and are filled with lead, all that is required, in case of a leak is recaulking of the lead joint thoroughly, some lead wool being added, if necessary. On rare occasions, when a pipe line is badly incrusted, it has to be cleaned. This is done either by chemical or mechanical processes.

910. Permissible grades in yards

In order to appreciate the implications of the grades permissible in yards, a brief analysis is given below.

The object of limiting the grade in a yard is to prevent a vehicle escaping from the yard whilst being hand or fly shunted, or if set in motion by the wind.

On certain down grades a vehicle moving at a certain velocity will come to a stop in a certain distance. On other down grades, the vehicles moving at a certain velocity will either accelerate or decelerate until it attains a particular (equilibrium) velocity and will continue to move at this particular velocity indefinitely, unless other causes change the velocity. Each down grade above a certain grade has this equilibrium velocity, which is attained when an equilibrium is established between the force on the vehicle due to grade and the vehicle or train resistance.

There exists no universally accepted formula for train resistance. In accordance with an Indian formula, the equilibrium velocity is 0 for a grade of 1 in 400, and 18 m.p.h. for 1 in 260, whilst a vehicle or train moving at any speed on 1 in 1000 grade on its own momentum will come to stop in a distance varying with the initial velocity.

The actual average value of vehicle resistance can only be obtained from tests on B.G., M.G. and N.G. separately and the equilibrium velocity as worked out from formulæ mentioned above will need revision when this is done.

The recommended grade is 1 in 1000 whilst the maximum grade is 1 in 400, equilibrium velocity for this latter grade being 0.

A vehicle or group of vehicles may be assumed to attain a maximum speed of 10 m.p.h. in fly or hand shunting, or due to propulsion by wind in a yard. The average speed under such conditions may be taken as not exceeding 5 m.p.h.

The distance required for a vehicle moving at 10 and 5 m.p.h. respectively on specified grades to come to a stop are as follows. These distances are the averages obtained from the formula

Grade	*Speed*	*Distance*
1 in 1,000	10 m.p.h.	1,970 ft.
1 in 1,000	5 m.p.h.	540 ft.
1 in 400	10 m.p.h.	10,500 ft.
1 in 400	5 m.p.h.	3,960 ft.

It is considered that in case of a grade of 1 in 400 in a yard, prohibition of either fly or hand shunting and prevention of shunting in the face of a train approaching in the direction of the lower end of the yard, is desirable.

In case of grades varying from 1 in 400 to 1 in 260 in a yard, some physical safety device, such as a *slip siding* (preferably with automatic spring points in case of multiple tracks) is considered essential. Prohibition of hand or fly shunting and shunting in

the face of a train approaching in the direction of the lower end of the yard is also considered necessary.

For vehicles provided with roller bearings, opinions appear to be divided as to the percentage reduction in resistance at various speeds effected with roller bearings. A reduction of 0.6 lb. per ton load was obtained by an American railway with 80-ton vehicles at 10 m.p.h. The resistance of both covered and empty wagons (10 tons weight) at 10 m.p.h. is 4.72 lbs. per ton load in accordance with Indian tests. The percentage reduction in resistance at 10 m.p.h. works out to 12.7. If 1 in 400 grade is considered an adequate limiting grade for vehicles with standard bearings, the corresponding limiting grade for vehicles with roller bearings is 1 in 460.

American experiments also indicate that friction at starting is reduced by 80 per cent. with roller bearings. The average starting friction for B.G. vehicles is 19 lbs. per ton load and this starting friction could be reduced to 3.8 lbs. per ton load with roller bearings. This would result in a tendency for vehicles provided with roller bearings to be moved more easily by wind than vehicles with standard bearings. Resistances on a down grade or even a level grade are inadequate to prevent free wagons with roller bearings being blown away, but this applies also to wagons with standard bearings. Normally precautions, such as fixing vehicles to the track with chains and sprags, adopted for vehicles with standard bearings, may be considered adequate for vehicles with roller bearings also.

Construction of Track

1001. Various methods of laying track

THERE are three distinct methods of laying a new track. The one almost always adopted in India is the telescopic method. Track materials are conveyed in material trains to the furthest point of the track, the materials are then unloaded and carried beyond the rail head and assembled. A further consignment of materials is brought to the advanced rail head and the operation is repeated.

The second method is employed if a temporary tramline has been laid for carrying out the earthwork. This tramline is used for conveyance of track materials. The track is assembled simultaneously at several points. A modification of this method is described in para 1005. If an additional track is to be laid by the side of an existing track, track laying on such "Doubling" schemes is carried out by this method for obvious reasons. In the third method, employed mostly in Britain and America, use is made of special track laying machines. There are two types of machines, one in which track material, carried in a material train, is delivered at rail head and laid in the required position by means of a projecting arm or jib, mounted on the truck nearest the rail head. The material train moves forward on the assembled track and the operation is repeated. In the second type of machine, fully assembled panels of track, each panel consisting of a pair of rails with the appropriate number of sleepers, are placed bodily on the ballast layer. The machine consists of a large cantilevered arm or jib, which projects beyond the wagon on which it is fitted. A panel of the assembled track is conveyed by a special trolly running

over the wagons of the material train, to the jib. It is lowered by the jib in the required position and connected to the previous panel. The track laying machine then moves forward and the operation is repeated. Over 700′ of track have been laid in one hour with such a machine.

Track laying machines are also used for renewal of track but their use for such work has been found to be too elaborate and their availability too restricted.

The use of cranes for track laying is on the increase and is being found to be very economical.

Various modifications of the three methods of *linking* are possible and are adopted to meet local conditions and requirements. For instance, (1) completely assembled panels may be conveyed to the site on trollies running on temporary tracks, a method adopted in Europe, or (2) mechanical devices such as *Anderson rail carriers* may be used for conveying rails, after unloading at rail head, to the actual site, or (3) a temporary tramline may be laid with the rails meant for the permanent track, sleepers and fittings distributed with the help of the tramline and the actual assembly of the track carried out after all the materials are distributed.

1002. Material depots

In any method of linking, the progress depends very much on the regular and correct supply of materials at the rail head. To ensure this supply, one or more material depots are established. The main depot is usually laid out at a convenient site near the point of junction of the new track with an existing railway. Rails, sleepers, track fittings, bridge girders and the numerous materials and plant required for the construction of the new railway, received in wagons from the existing line, are unloaded, sorted and prepared at the main depot. The layout of the depot should be such that wagons can be unloaded and removed expeditiously. Mechanical devices, such as cranes, for unloading heavy materials may be employed, but simpler expedients are more economical and equally effective.

For instance, the depot sidings may be laid in cuttings of such depth that the floor of the wagons are at the same level as that of the stacking ground. Rails and other heavy materials can then be easily pulled in or out of wagons.

Preparation of material, such as adzing and boring of wooden sleepers, cleaning and oiling of fishbolts, threading of fishbolts through pairs of fishplates to prevent loss, should be done at the depot. Stocks of rails and sleepers should be kept in such a way that the correct number of each may be loaded easily in the

material train for conveyance to rail head. The required quantities of materials are loaded in a *material train* in the depot and despatched at regular intervals, usually of a day, to the rail head. A minimum of two sets of wagons are necessary. Whilst one set is at the rail head, the other set is loaded at the depot. The number of engines required depends on the distance of the rail head from the depot. If the distance is such as to enable a material train to be taken to rail head, unloaded and brought back to the depot within a day, one engine will suffice. Sufficient margin has to be kept in the time-table for delays, due to derailments and other unforeseen items, as the track over which the material train has to run is not sufficiently consolidated. The margin should be considerably increased during the rainy months.

If the distance from the depot to the rail head becomes too great to permit the material train to make the round trip from the depot to rail head and back on the same day, it is advantageous to establish a subsidiary depot nearer the rail head. The main depot may then be retained for materials other than track materials. The main depot may also be used for storing track materials, surplus to immediate requirements at rail head, as manufacturers cannot be expected to regulate supply strictly according to the progress of linking.

In order to avoid unnecessary handling of materials, arrangements should exist by which wagons, with materials received from manufacturers, may be incorporated in the material train and despatched direct to rail head.

Despatch to rail head of the correct number of rails, sleepers and fittings is essential if progress is not to be retarded and if surplus materials are not to be scattered along the track.

The material train conveying the materials to rail head must be marshalled in the correct order, otherwise delays, unnecessary handling and longer lead are likely to occur at the rail head. The material train should also run strictly to a time-table, which would need alteration from time to time, due to the lead becoming longer with the progress of linking. Punctual running of the material train should be insisted upon and steps taken to ensure this. It must be realised that any delay in the supply of material is likely to result in a large number of men at the rail head being kept idle. Detailed and thorough organisation is the secret of rapid progress in linking. No item is too small to be overlooked. Even such details as the proper nesting of rails in wagons has a bearing on the progress. Even a few missing fishbolts may prevent a number of rails being linked up, with consequent delay. Linking may be compared conveniently with the belt system in a factory. Failure

at one point slows down work at all other points. Thorough organisation is the only guarantee against such a failure.

1003. Telescopic method of linking

In this method of linking, used invariably in India, rails, sleepers and fittings are unloaded from the material train as close to the rail head as possible. The sleepers are carried either in carts or by men along the adjoining service road and spread on the ballast. The rails are taken in pairs to the end of the last pair of connected rails and linked. The rails were formerly carried by men either on their shoulders or with the help of *rail slings*. Carrying rails is strenuous work and it necessitated the rails being unloaded as near the rail head as possible, in order to reduce the load. This could only be done by working the material train forward as the linking progressed. *Anderson rail carriers* have simplified this strenuous work, enabled work to be speeded up and reduced the cost of linking.

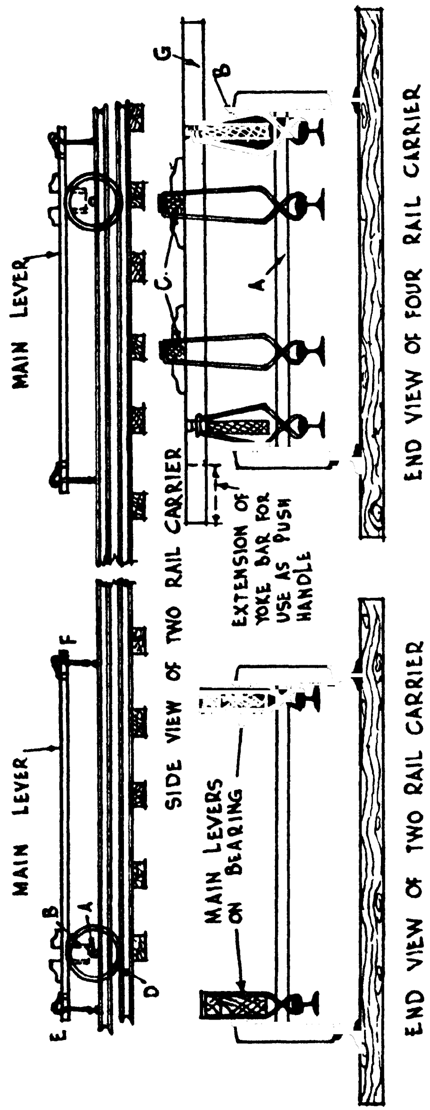


Fig. 1003

An Anderson rail carrier (Fig. 1003) consists of two levers

EF with fulcrum blocks B, supported on trolly axle at A, the ratio of FA to EA being 10 to 1. The levers are provided with scissors type clips which grip the head of a rail. The complete carrier consists of a pair of axles with two levers on each axle. For lifting the rails, end E is lowered and the scissors clip attached to the head of the rail. End F of the lever is then pulled down; the rail end at E is thus lifted and the clip at F is attached to the head of the rail. When the rail is held by four clips, two from a lever on each axle, it is ready for transport. Two rails are picked up simultaneously. Carriers to convey four, and even six rails, at the same time are also employed. The additional levers C are fixed on a fulcrum bar G, which is placed on top of the fulcrum blocks B and is sufficiently high to clear the wheel flanges. The additional levers are not fixed on the axle but on fulcrum bar G, in order to concentrate the load as near to the wheels as possible, to avoid bending of the axle.

The two-rail carrier is used for conveying the rails immediately ahead of the last pair linked. This is done with the help of a temporary track for carrier wheels. This temporary track consists of $3'' \times 3''$ angle irons of the same length as the rails, resting on the track sleepers and held to the last linked rails with pins and cotters.

After the rails are unloaded from wagons on the cess and slopes of the formation, they are levered with crowbars into the inter-rail space. The rails are then picked up with the two-rail carrier and deposited just ahead of the last pair of linked rails. When the distance increases between the point of unloading and the rail head, a four or six-rail carrier is employed, in addition to the two rail carrier, for taking the rails as close to the rail head as possible. When these carriers are employed, it is not necessary for a material train to remain all day long at the rail head. Materials are unloaded at one place and the empty train returns to the depot.

1004. An example of linking

The track to be linked consisted of 90 lbs. R.B.S. rails, 36′ long, on $(n+3)$ steel sleepers with clips and bolts. A material train which ran between the depot and rail head was scheduled to convey materials, sufficient to link at least half a mile of track every day.

The train was marshalled so as to have all the rail trucks in front, followed by the sleeper wagons; the engine was attached in the rear. Fishplates and bolts were distributed in the rail trucks,

the bolts being threaded through the fishplates to prevent loss. To avoid double handling, wagons received from manufacturers were incorporated in the material train as far as possible and despatched to rail head. The train ran according to a time-table which was changed at short periods to meet varying conditions, such as the daily increase in distance of rail head from depot. Two sets of wagons were essential for this work but one engine sufficed.

The loads were detached at rail head in the evening and the materials unloaded so as to be ready for next day's linking. Sleepers were carted at night, the cartmen preferring night work to avoid the heat of the day. All materials brought to rail head were unloaded at one place and, as a result, hand lead increased as linking progressed during the day. Keeping the engine with the wagons at rail head and unloading small lots of materials, would have considerably diminished hand lead and thus accelerated progress. This, however, would have required another engine to get the second set of wagons ready at the depot for the next consignment of materials and the saving effected by the increase in progress would have been far outweighed by the cost of an extra engine and staff. Moreover, there are limits to the method of frequent unloading in small lots and it was found that time was actually lost if less than 40 pairs of rails were unloaded at a time. This loss was occasioned by the linking party having to stop work whilst the train was led to the furthest point possible, the materials unloaded, the train drawn back and the rails transferred within the track. It also took a little time for the men to get into their stride when linking work was restarted.

On arrival of the train at rail head, three parties of sixteen men each boarded the rail trucks and unloaded the rails by wedging them out with crowbars and throwing them over the side. If the rail head happened to be within a short distance of the depot, i.e. within ten miles, the engine had a little spare time and waited at rail head till the rails were unloaded and then pulled the wagons out clear of the site of unloaded rails. When the engine could not afford this time, due to increased distance between rail head and depot, it detached the sleeper wagons some distance behind the rail trucks. On unloading of rail being completed, the empty rail trucks were hand-shunted and attached to the sleeper wagons by the linking party, to clear the site of unloaded rails for working the rails carriers. The unloading of sleepers was done by a contractor who carted and spread these in advance of rail head. These sleepers were laid on two parallel ridges of moorum, or hard soil, which had been formed on top of the formation. In

cuttings, stone ballast, wherever conveniently available, was used in place of moorum. Fishplates and bolts were distributed in advance, at appropriate-positions of joints.

The rails were transferred by two sets of men from outside the track, where they had been unloaded, to the centre of the track in order to enable them to be picked up by Anderson rail carriers and taken to the furthest pair of connected rails. The two-rail carrier conveyed the rails to the end of the track and over a pair of angle irons attached to the furthest rails with pins and cotters. The wheels of the rail carrier ran over the vertical edges of these angle irons, the rails were deposited between these and the rail carrier returned for a fresh supply.

The angle irons were then disconnected from the rails and dragged forward to the end of the rails deposited by the carrier. The newly deposited rails were placed in their correct position with the help of crowbars. Appropriate liners were put in between the ends of rails for correct expansion gaps and the fishplates fitted. The men on this work moved forward to cope with a fresh pair of rails and a batch of clip turners took their place. These turners fixed the foot of the rails between the clips on the sleepers.

The clip turners were followed by two men marking the correct spacing of sleepers on the rails and four men worked the sleepers with crowbars into their positions, from which they had been disturbed whilst fixing the rails. All these, in turn, having moved forward, a large number of men came up for tightening the clip bolts, and took particular care of the correct position of the "feathers" on the bolts to ensure correct gauge.

The tools used by clip turners and bolt tighteners consisted of spanners, fifteen-inch tommy bars, wooden blocks and crowbars. Both the clip turners and the bolt tighteners worked in sets of three, one man manipulating the spanner, whilst the second man wedged the tommy bar in between the clip and the saddle of sleeper to prevent the bolt from dropping out of place, with consequent shifting of the "feather" on the bolt. The third man raised the sleeper with crowbar and wooden block to the foot of the rail.

In front of the men manipulating the angle irons, two men set out the centre line with strings, attached to pegs fixed previously, and chalk-marked the centre of each sleeper. These were followed by four men adjusting the sleepers to correct position with regard to the centre line. The spacings of sleepers were permanently marked on the angle irons and as soon as these were dragged forward, the sleepers underneath were spaced according to these marks.

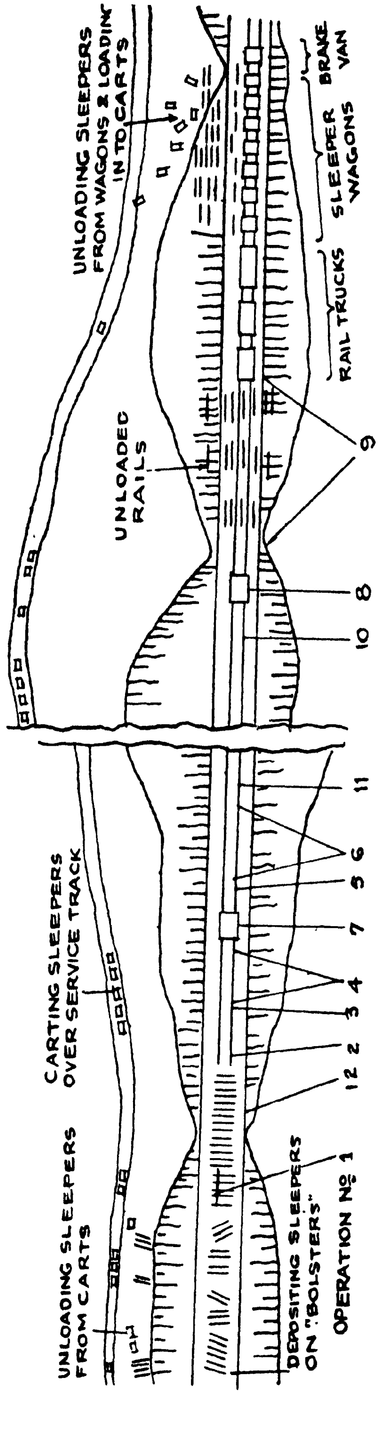

UNLOADING SLEEPERS FROM CARTS
DEPOSITING SLEEPERS ON "BOLSTERS"
OPERATION No 1
CARTING SLEEPERS OVER SERVICE TRACK
12
2
3
4
7
5
6
11
10
8
9
UNLOADED RAILS
RAIL TRUCKS
SLEEPER WAGONS
BRAKE VAN
UNLOADING SLEEPERS FROM WAGONS & LOADING INTO CARTS

Fig. 1004

Slewing of the track to correct alignment was done by a gang which brought up the rear. When the distance, from the point of unloaded rails to rail head, increased, a four-rail carrier was introduced and this brought the rails about two-thirds of the distance to rail head, thus shortening the run of the two-rail carrier. With further increase in the distance, another four-rail carrier was brought into operation.

Factors which governed the rate of progress were the speed of rail supply by the two-rail carrier and the speed with which fishplates were fixed to rails. During the earlier part of the day's work, the second factor predominated, whilst with the increase in distance of rail head from unloading point, the rail supply was all-important.

The distribution of labour is given in a tabulated form and Fig. 1004 shows the position of various works.

Work	No. of men	Nature of work
1. Straightening sleepers ..	6	2 men tied centre line strings from peg to peg and chalk-marked the centre of each sleeper. 2 men brought these sleepers into correct alignment and 2 men adjusted them to their correct spacings. First 4 men were two rail lengths in advance of the angle irons.
2. Working angle irons.. ..	4	2 men per angle iron to drag them forward, and hold them the correct distance apart, whilst the rail carrier was travelling on these.
3. Fixing fishplates	6	1 keyman with two helpers on each rail. Correct expansion gap was obtained by wedging out the loose rail or driving it home against a liner of required thickness with the angle iron as a ram. Whilst 2 men fixed the plates, the third raised the rail end, as desired, with a crowbar.
4. Clip turning	36	These men worked in sets of three. One, with a crowbar, held the sleeper in position, whilst the remaining two applied themselves to the outside and inside clips. These men did not fully tighten the nuts but left the clips loosely fitted.

Work	No. of men	Nature of work
5. Adjusting sleepers .. .	4	The handling of sleepers by clip turners disturbed the sleepers from their correct position and two men with a gauge, chalk-marked on both rails, the position of each sleeper, whilst two more adjusted the sleepers to their correct position.
6. Bolt tightening	42	4 keymen tightened the fishbolts and removed the expansion liners and 36 men tightened the clip bolts.
7. Working two-rail carrier ..	7	3 men for each rail with one man in charge; this man ran in front of the carrier, warning the men off the track.
8. Working four-rail carrier ..	20 (for 2 carriers).	One set of 10 men, with one four-rail carrier, employed until lead justified the use of the second rail carrier. When not working the rail carriers, these men slew the track and transferred unloaded rails within the track.
9. Transferring rails with the inter-rail space	10	The rails unloaded outside the track from wagons were levered into the inter-rail space, to permit rail carriers to convey them to rail head.
10. Slewing track.. .	8	These men brought the track to correct alignment and packed where necessary.
11. Fixing sleepers found short in track	4	These men made good any sleepers found short in the track.
12. Distribution of fishplates and bolts (women)	10	Fittings were distributed at positions of rail joints by these women.
13. Unloading rails	48	The men were taken from those turning and tightening clips and transferring rails (operations 4, 6 and 9). When unloading was in progress, linking had to be stopped, to allow unloading being done as near the rail head as possible.

Making allowances for additional miscellaneous works, such as picking up materials, cutting rails on curves, and for casual absence, 225 to 250 men may be expected to link half to two-thirds mile per day, provided there is no hitch in the supply of materials.

Another 50 men may be added for slewing, initial packing and boxing the same length of track.

The actual progress per working day with the distribution of labour shown above, two sets of wagons for materials and one engine, averaged between half and two-third mile. The actual figures for one month were 0.69 mile average per working day.

The cost for this particular month, for the linking operations described above, was found to be 77 per cent. of the cost of carting and spreading sleepers.

Maximum progress per day was 210 pairs of 36′ rails, or 1.43 track miles. Following are some of the deductions from the work done on the day of maximum progress.

(1)	Maximum rate of linking per hour	23.22 pairs of rails.
(2)	Average rate of linking per hour (excluding time for unloading rails)	17.68 pairs of rails.
(3)	Average rate of linking per hour (including time for unloading rails)	14.24 pairs of rails.
(4)	Labour employed on the day of maximum progress	276 men and 10 women.
(5)	Percentage of time taken in unloading rails to total time of linking	24.6 per cent.

1005. Linking with the help of a temporary tramline

The essential difference between this system and the telescopic method, described above, lies in the conveyance and spreading of sleepers.

The recognised method of spreading sleepers in India is for a contractor to cart these over service roads, distribute them along edges of banks and cuttings and subsequently spread them on the cess. This system is liable to a complete breakdown in heavy rains as the fair-weather service track turns into a quagmire after the passage of a few loaded carts.

In such a contingency, the rails may be linked to a gauge of 2′ or 2′-6″ on junglewood logs, only three logs being used per rail

length. Tramway wagons converted to carry rails, may be hauled over this 2′ track with tramway engines, for conveying a further supply of rails. When a certain length is completed to this gauge, sleepers may be carried in the same wagons and distributed along the track. The conversion of 2′ gauge to the standard 5′-6″ gauge can then be carried out without any difficulty.

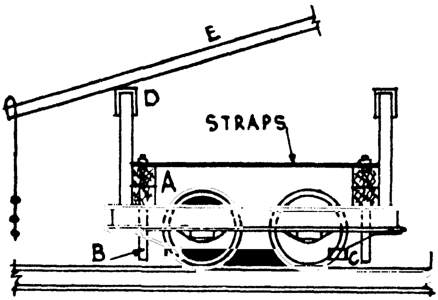


Fig. 1005

A successful application of this method is described below. The conversion of tramway wagons for conveyance of rails, weighing nearly half a ton each, was effected by removing the hoppers from the wagons. Timbers A (Fig. 1005) were fixed at either end of the truck and within the hopper supporting frame. Three metal slings B were suspended from each of these timbers and the rails, which were to be conveyed, rested in these slings. The suspended rail in the middle acted as a drawbar with the help of jaws C, fixed to the truck. A pin was passed through one of the fishing holes in the rail and holes in the two arms of the jaw. As it was intended that the wagons should in no way be damaged by this conversion, no rivets were used, or holes drilled for bolts. The sling timbers were therefore fixed with hook bolts, metal straps being used to prevent their displacement. The rails were put into the slings by lifting them with lever E, resting on fulcrum D, fixed to the hopper supporting frame. The slings, which were hung from hooks, were drawn to one end, whilst the rail was lifted to the correct position and the sling was then slipped on. The conveyors worked in pairs and the end conveyors had a counterbalance to equalise the weight of rails, suspended at one end. It should be noted that the rail conveyors could be considerably simplified if specially designed for this work.

In the loading depot, a three-rail track was laid, thus permitting both the 5′-6″ and 2′ gauge wagons to run over the same length. Rails were unloaded from broad gauge wagons and transferred to the 2′ inter-rail space. Rail conveyors were brought in position to the end of these rails which were then lifted with the help of levers and placed in slings. Whilst lifting, the wagons had a tendency to rise at the free end; this was prevented by the men in charge of the levers standing on the frame at the free end. Semi-diesel

locomotives were used for hauling the loads, their capacity being 8 to $8\frac{1}{2}$ tons up a grade of 1 in 150. Fifteen rails, complete with the fittings, could, therefore, be carried per trip. The track was laid on half-round sleepers (3 per rail length) collected from local jungles. Rail carriers, similar to Anderson carriers, were employed and the procedure at rail head was similar to that described in para 1004.

For linking to 2′ gauge 80 men and 10 women were required and the average rate of progress per working day was 0.3 mile. This is not a high figure but the progress was hindered by lack of sufficient hauling power. In course of this linking, 4 spans of 40′ girders, 5 spans of 20′ girders, and 1 span of 12′ girder had to be erected. Two special bogies were designed and the girders conveyed with the help of these over a distance varying from 3 miles to $8\frac{1}{2}$ miles. Sleepers were conveyed on the tram wagons and distributed along the 2′ gauge track. The removal of rails from the tram track, spreading of sleepers and fixing of rails to 5′-6″ gauge, call for no special remarks.

1006. Initial consolidation of track

It is not considered good practice to spread stone ballast on new banks built manually, as a considerable quantity of stone sinks in the soft earth and is lost. The track is usually packed with moorum, decomposed rock or other suitable material available locally.

When the banks have been sufficiently consolidated, by the rolling of trains, a year or so after the opening of the line to traffic, stone ballast is introduced. The original moorum layer then forms a blanket below the ballast, and this is an advantage for future maintenance of the track, particularly if the banks are made of poor soil. On the other hand, if stone ballast is easily available along the alignment, it is economical to spread stone ballast in new cuttings as there is little likelihood of the stone ballast sinking into solid earth. Cuttings in black cotton soil, however, are treated in the same way as banks. The moorum or other suitable material if available at site is spread on the formation in a layer a little wider than the sleeper or in two parallel ridges, each about 12″ high and 3′-6″ wide at top, so that each ridge comes under the rail seat. After the track is linked, it is consolidated on the moorum sufficiently to permit material and ballast trains to proceed at a slow speed.

Additional moorum or suitable material is then unloaded from ballast trains and the track lifted and packed. As heavy lifts are

necessary, bully (pole) levers, fulcrum blocks and boards described in para 1107 are used. The track is lifted a few inches above the final rail level and the gradual sinking with the passage of trains, brings it to the correct level. Heaping up of moorum by hand under trough sleepers has been found to be more effective for lifting of track, than packing with beaters. The reason is, that the hard core formed under the trough with the passage of trains, is not broken, as is the case when beaters are used. Also, if the moorum is wet it has a tendency to stick to the beaters. In hand packing, the sleepers are levered up and this provides a wide gap between the bottom of the sleepers and the top of the existing core. Loose moorum is piled on the core, under the rail seat and the track is then lowered. The operation is repeated on the opposite rail. Details of work done by this method are given below.

Two men in advance having loosened the moorum round the sleepers ends, the track was levered up with a pair of bullies as described in para 1107. The distance between the levers was governed by the condition of the soil, wet soil requiring both levers within a rail length. Eighteen gangmen concentrated at the free ends of the levers, pulling down these ends and thus raising one side of the track. After the lever was pulled down so that it touched the near rail, three men were detached to sit at the far end of each of these levers to hold the track in the lifted position. Three men supplied moorum already loosened, two men proceeded ahead for loosening further moorum and the remaining 10 men heaped moorum under the trough sleepers and worked it in the troughs with their hands. This hand packing was done from the end of the sleeper to twelve inches inside the inter-rail space. The process was repeated with the opposite side of the track after every five or six rail lengths.

Dressing and slewing of the track was done simultaneously, 16 men or less slewing according to the condition of track and the remainder dressing to section shown in Fig. 604*a*. A clearance was left between the foot of the rail and the surface of the moorum to drain rain water; the ridge in the centre prevented its accumulation. On an average, a gang of 25 men could lift, pack, slew and dress about 19 rail lengths per day on dry bank.

After the passage of one or more trains, the irregularities in settlement were levelled out by finer packing with wooden beaters. Wooden beaters with larger heads are more suitable than steel beaters for this final packing. Lifting and packing of track in waterlogged banks has been made possible by the method described above, and heavy lifts in dry weather can be given in a fraction of the time required with beater packing.

Following is a brief note on a programme for the supply of additional moorum ballast and the consolidation of track in dry weather, adopted on a newly laid track. Labour was divided into resident gangs and train gangs. Resident gangs were given a length varying from two miles to six miles, depending on the condition of the track and situation of labour camps. The duty of the resident gangs was to pack the track on stone ballast in cuttings, and bad patches on moorum ballast on banks.

Train gangs, of which there were three, with a total strength of 75 men, followed the ballast train, consisting of 15 wagons. Loading of moorum at depots and unloading was done by contract. The quantity unloaded was at the rate of 4 cubic feet per foot length of track, 10 cubic feet per foot of track having been spread prior to linking. The train made two trips one day and one trip the next day, half its second day being used up for other works such as conveyance of materials to different centres. Moorum from each of the first two trips was spread over 48 rail lengths. The third trip was unloaded over 12 rail lengths, the remaining moorum being distributed where required in the length of the two previous trips. Hence the length covered by the three trips, occupying two days, was 108 rail lengths or about $\frac{3}{4}$ mile.

As each gang packed, slewed and dressed about 18 rail lengths per day, in dry weather, the three gangs were able to complete work on this $\frac{3}{4}$ mile in the same period of two days.

1007. Track material per mile of track

It is very necessary to work out the exact number of rails, sleepers and fittings required per mile of track. The figures are obtained easily as follows :

(1) To obtain the number of rails, divide 5280 by the length of the rail and multiply by 2.

The number of 42′ rails per mile of track is $\frac{5280}{42} \times 2 = 252$ (to the nearest full rail).

Actually 252 rails will cover 5,292′.

The weight of rails per mile of track is also useful, to enable the number of wagons required for the transport of rails to be obtained.

The weight of rails in tons per mile of track is equal to the number of rails $\times$ length $\times$ $\frac{\text{weight of rail per yard}}{3 \times 2240}$.

The weight of 90-pound 42′ rails for a mile of track is therefore $\frac{252 \times 42 \times 90}{3 \times 2240} = 142$ tons nearly.

(2) The number of sleepers per mile are obtained approximately from $\left(\frac{\text{No. of rails per mile}}{2}\right) + \left(\frac{\text{length of rail in feet}}{3} + x\right)$.

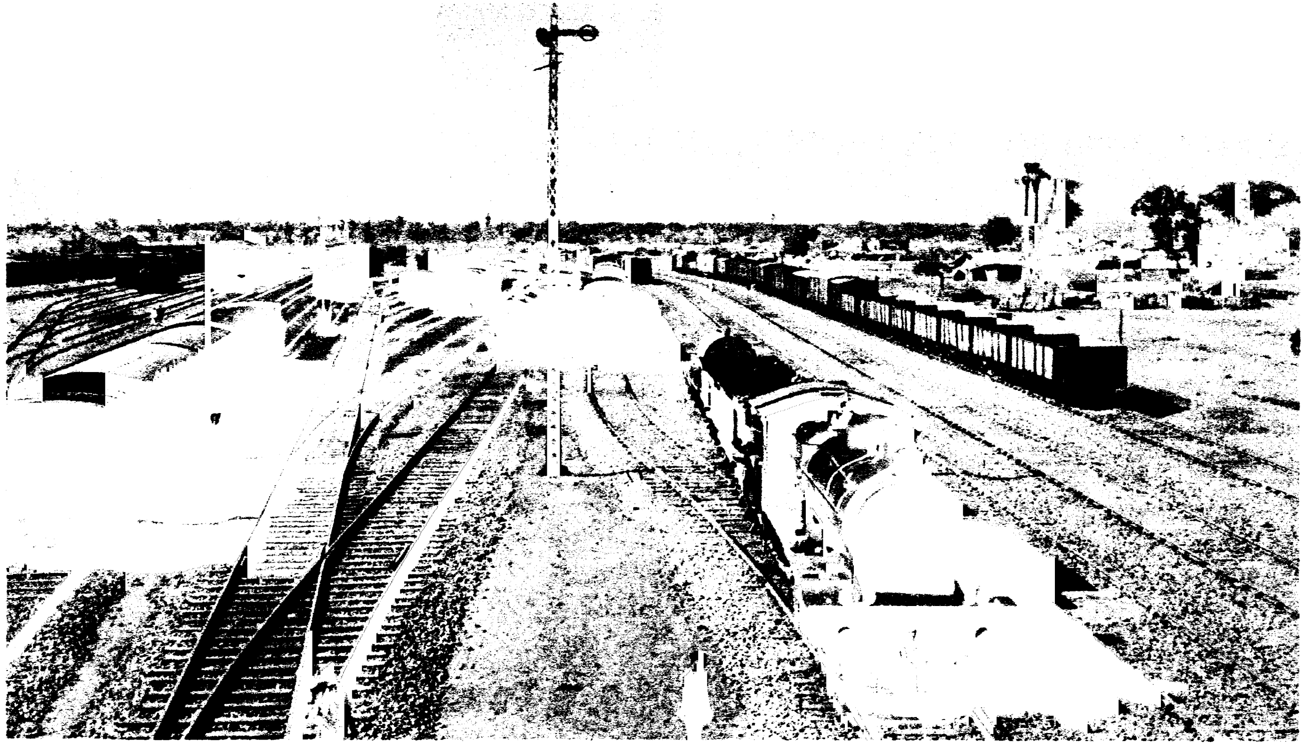
If $x = 3$, as in $(n+3)$ sleepers, the approximate number of sleepers with 42′ rails per mile of track is $\frac{252}{2}\left(\frac{42}{3}+3\right) = 2{,}142$.

(3) The number of fishplates is equal to double the number of rails and the number of fishbolts is four times the number of rails.

For 90-lb. 42′ rails, the number of fishplates is 504 and the number of fishbolts is 1,008 per mile of track.

PART 3

Maintenance and Renewal



A marshalling yard. Two sets of gathering lines are visible

CHAPTER 11

Maintenance of Track

1101. Essentials of maintenance

A RAILWAY track has to be kept in such a condition that trains may run over it in safety at the highest prescribed speed. Unless the engines and vehicles move over the track smoothly, considerable wear and tear of vehicles as well as of the track takes place, great discomfort is felt by the passengers and damage is done to the materials carried in vehicles. Safety is to a very great extent dependent on the riding qualities of the track.

The railway track is an elastic structure and its resiliency has to be maintained if bad running and heavy wear and tear are to be avoided. The position or alignment of the track has to be accurate if side thrusts, with all the troubles that follow in their wake, including, in extreme cases, the possibilities of derailment, are to be averted. Defects in the surface or level of a track lead to swaying, bumpy riding, heavy wear and tear, and various other

ills. Curves are more difficult to maintain than straight lengths and several special items, such as correct superelevation, have to be looked after. As the track is not a rigid structure, defects, unless attended to without delay, develop quickly. Constant supervision and sustained effort are required from everyone responsible for track maintenance. In this and the following chapters, the numerous items that have to be taken care of, the various defects which develop in the track, their causes and remedies, methods of inspection and the way in which the track is maintained in an efficient condition are explained.

The essentials of good maintenance are (1) the determination of the factor or factors responsible for bad running at any particular spot and correction of the defects, (2) constant attention to the track to prevent such defects from arising, and (3) periodical overhaul of the track.

Maintenance of a track may be broadly divided into maintenance of surface, alignment, drainage and track materials.

In India, by far the greatest portion of maintenance work is done manually. In America, on the other hand, mechanical appliances are used in almost all the items of trackwork. Abundance of labour and dearth of mechânical appliances have been the chief reasons for the prevalence of manual methods in India, but considerable advantage can be obtained by using simple machines. Devices, such as track lifting jacks, sleeper or tie tampers, and drilling machines, help considerably in maintaining a track in excellent condition. Improved methods of maintenance are essential for the high speeds and heavy axle loads.

1102. Packing

The two rails of a track must always be kept in the same plane, or surface, whether the track is on a rising gradient or falling gradient or on a level stretch. This applies to straight lengths of track only. On curves, the outer rail is kept at a prescribed height above the inner rail. This height is kept constant throughout the curve with the exception of the two ends of the curve where it is reduced at a constant rate, so that the difference in the height of the two rails becomes zero at the end of the curve or a short distance beyond the end of the curve.

The composition of track structure and the nature of the loads to which it is subjected are such that the ballast under the sleepers gets loose and numerous depressions are formed in the plane of the rails. The joints are particularly affected due to the constant

blows received by the joints from passing wheels. Whole rail length are pressed down and form sags due to the ballast getting loose on account of vibration or on account of the soil in the formation being soft. Sometimes, one rail is depressed more than the other rail and vehicles passing over such a length sway from side to side. Slight irregularities in surface, if not corrected immediately, assume serious proportions rapidly and one of the most important work of men looking after the track, is to constantly attend to the surface of the track. Packing consists of ramming and thereby interlocking stones to form a compact mass, sufficiently consolidated to bear the loads of trains passing over it. Such compacted ballast has the requisite resiliency.

The procedure adopted in packing ballast under sleepers is as follows : The ballast round the sleeper is pulled aside, with ballast forks or shovels; ballast is thus removed to a depth a little below the bottom of the sleeper. Ballast is then packed under the sleeper with pick-axes, having one heavy blunt end and known as *beaters*, until the level of the rail is raised to the required height. The sleeper is not packed throughout its length, but from each rail seat to the end of the sleeper and an equal distance in the inter-rail space. The packing under the rail seats should be done first and care should be taken not to strike the sleeper with the beater, whilst packing. The sleepers should be sufficiently far apart so that the sweep of the beater is not hindered by the adjoining sleeper.

A sleeper may be packed by one man, but when this is done, the sleeper is likely to have an uneven bearing. A better method is to position two men, back to back, on the same sleeper, one man in the inter-rail space and the other on the shoulder, and to make them pack diagonally under the rail seat. This is sometimes known as "*scissors packing.*"

In order to ascertain whether each sleeper has been packed to the correct level, the mate or foreman of the packing gang bends down so that he can cast his eye along the top of one rail. Depressions are easily spotted and further packing is done under the depressed sleepers. For reasonable accuracy, sighting should be done from at least 50 feet from the rail which is being checked. Sighting boards are sometimes used for arriving at the correct rail levels. A sighting board and a target board are fixed at two high points on the rail, a reasonable distance apart. An intermediate board is then held at several points, usually at rail joints and at the centres of the rails. The sighter instructs the man in charge of the intermediate board to raise or lower it, so that the top of this board is brought to the same level as a line on the target

board when observed from the sighting board. The sleepers are then raised or lowered, as required. After having packed under one rail for a short distance, packing is done under the opposite rail and to ensure the rail being brought to the same level as the first rail, a *level board* with a *spirit level* (Fig. 1102*a*) is placed across the two rails. The unpacked rail is lifted by packing or lowered by loosening the ballast under the sleeper and packed again till the bubble in the spirit level becomes central. When checking cross levels over a curve, a small stepped piece of wood, known as a *cant board*, is placed under the level board at the inner or lower rail (Fig. 1102*b*). The level board is placed on the step corresponding to the correct superelevation and the sleeper is packed sufficiently to bring the bubble in the spirit level to the centre.

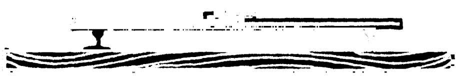


Fig. 1102*a*

When a sleeper is to be lifted more than a fraction of an inch, a crow or claw bar is applied at the end of the sleeper and the sleeper is levered up to the required level. A block of wood, or a piece of scrap iron, or even a hard piece of stone is used as the fulcrum. The leverman holds the end of the sleeper at the required level whilst ballast is packed under the sleeper.

Track lifting jacks or rail lifters are used with advantage when considerable portions of the track are to be lifted. A jack is more economical than levers, as only one man is required for working the jack whilst several men may be necessary with crowbars. Track jacks have projecting pieces near the base on which the foot of the rail is lifted, the sleeper being pulled up with the rail. They have a trip arrangement by which the track can be dropped instantaneously. The jacks should not be fixed in the inter-rail space but always on the outside of the rail. Both rails should be lifted simultaneously to avoid unnecessary strain in the track and its liability to move out of position if only one rail is raised. After the sleepers have been raised in this way, the ballast is pushed under the sleepers with shovels or forks and finally packed with beaters. Occasionally, for heavy lifts, wooden poles (bullies) or short lengths of light section unserviceable rails are used as levers. A disadvantage with levers is that they are apt to push the track out of alignment when making heavy lifts. Track jacks are far more satisfactory, expeditious, and economical.

For checking purposes, it is usually sufficient to read cross levels at the joints and at rail centres, as the rails are sufficiently stiff to retain the intermediate portions at the correct level. It is

desirable, when checking, to fix the level board on the two rails directly over a sleeper.

It is good practice to pack the rail joints first, then the centre of sleepers in each rail length, followed by the intermediate sleepers. As joints are the weakest links in the track and are subjected to constant pounding, the packing under joint sleepers gets loose sooner than under other sleepers. Loose packing at joints not only produces poor running but has a considerable adverse effect on the rail ends and on fishplates and should be attended to without delay.

On curves, the inner or lower rail should be levelled first and the outer rail given the correct superelevation with the cant and level boards and spirit level (*vide* Fig. 1102*b*). Permanent reference pillars are invariably provided at a fixed distance from and on the inner side of curves, particularly at the tangent point. Such a pillar usually consists of a piece of rail embedded in concrete and with a notch cut in it. The depth of the notch is made equal to the superelevation, and the bottom of the notch is kept at the same level as that of the inner rail.

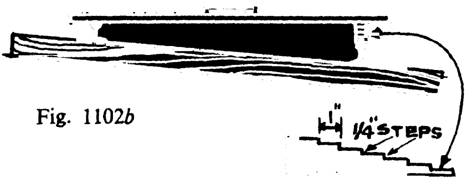


Fig. 1102*b*

Since the packing at rail joints suffers most, it is usual to pack the joints slightly higher than the rest of the rail. The tendency of mates to overdo this, results in *riding* joints.

Pot sleepers are packed with steel bars through holes in the body of the pots kept for this purpose. The method of packing is satisfactory so long as only slight packing is required. For heavy packing and lifting, the ballast should be packed under the rim of the sleeper. Packing under the rim is also found to be more effective when pot sleepers are on formation containing poor soil.

The surface of a track deteriorates with the passage of trains over it. The deterioration is not uniform; some places become much, worse than others and the extent of deterioration depends on the soil, track materials, standard of maintenance etc. Work done, in attending to the bad places, is known as *spot surfacing* or *picking up slacks*. Rail joints need by far the greatest attention and spot work invariably includes packing of joint sleepers. For a quick general improvement in a deteriorated track, picking up of low joints and packing the centres of rails, produce satisfactory temporary results. Looseness in fishbolts has an adverse effect

on joint packing, apart from increased wear of the rail ends and fishplates. If the fishbolts are loose, the depression at the trailing end of the rail under the wheel load is increased and the blow caused by the wheel jumping on to the receiving end of the adjoining rail is also considerably augmented. A series of such blows loosens the packing under the joint sleepers. The loose packing results in heavier blows and the joint deteriorates at an increasing rate. It is therefore essential to keep the joint sleepers always thoroughly packed and the fishbolts adequately tight.

Packing of joint sleepers does not necessarily mean packing of one sleeper only on either side of the joint. It may be necessary to pack two or more sleepers on either side of the joint, depending on the amount by which the joint is depressed. With cast iron pot sleepers it is essential to pack more than one sleeper on either side of the joint, otherwise the joint will ride hard and the pots at joints are likely to be broken.

It may be mentioned that appearances are sometimes deceptive. The surface of a portion of a track may appear perfect, yet the riding over it may be rough. This is due to invisible voids. Packing under a number of sleepers may be loose, but due to the stiffness of the rail, the sleepers instead of firmly bedding on the ballast may remain suspended from the rails. Only when wheel loads are applied, the rail is depressed. Packing every sleeper is an effective remedy.

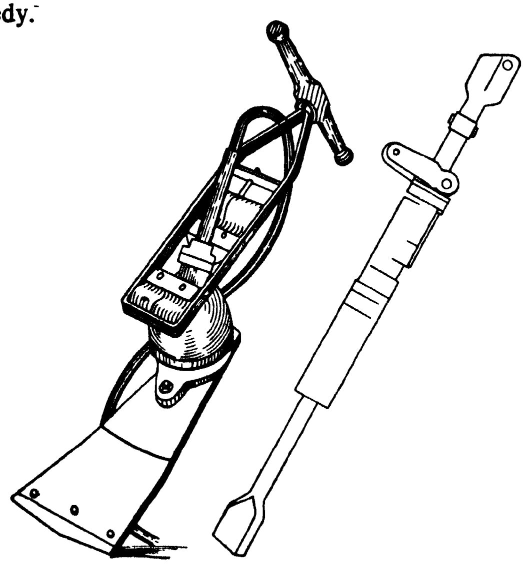


Fig. 1102c

Usually sags in lengths of tracks are removed by lifting and packing. When there are a few isolated high spots, with the rest of the length a long sag, it is quicker in spot surfacing to lower such high spots, by loosening the ballast and repacking, than to lift the sagged length.

Spot surfacing can also be done by lifting the low sleepers, spreading uniformly the correct quantity of ballast under the sleepers and letting the trains do the packing by rolling. This method is not used in India and has serious drawbacks. It is difficult to judge the correct quantity and unless the correct quantity is used the results are unsatisfactory.

In case of a track with long welded rails, packing should be avoided at temperatures greater than that at which the rails were laid, or destressed.

Packing is done in America, mostly with pneumatic, and sometimes with electric tie tampers (Fig. 1102*c* right). Pneumatic tie tampers consist of percussion hammers fitted with short tamping bars having flat heads with a slight incline. Each tamper is held by one man and worked by compressed air. Air is supplied to the tampers through lengths of rubber hose from an air compressor worked by an internal combustion engine. The whole set is portable and each compressor can supply air to a number of tampers simultaneously, the number depending on the capacity of the compressor. The tamper gives rapid blows to the ballast by means of compressed air and packing done with the machine is much quicker and more effective than with hand beaters. Approximately

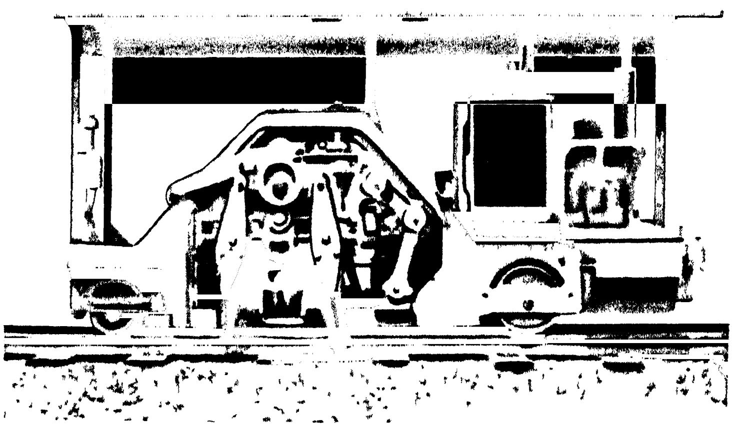


Fig. 1102*d*

two minutes' tamping is sufficient for each sleeper. Tie tampers have been used experimentally in India. With tie tampers, ballast does not have to be removed to the level of the bottom of the sleeper as is the case when beaters are used. The tool is held at a slight angle from the vertical and works its way down, packing the ballast uniformly. With *Vibration tampers* (Fig. 1102*c* left) packing is done by very rapid vibration of the blade. Such tampers are easier to handle than percussion tampers.

Tamping machines such as the one illustrated in Fig. 1102*d* give excellent and rapid results. Fig. 1102*e* illustrates the movements of the blades of the machine.

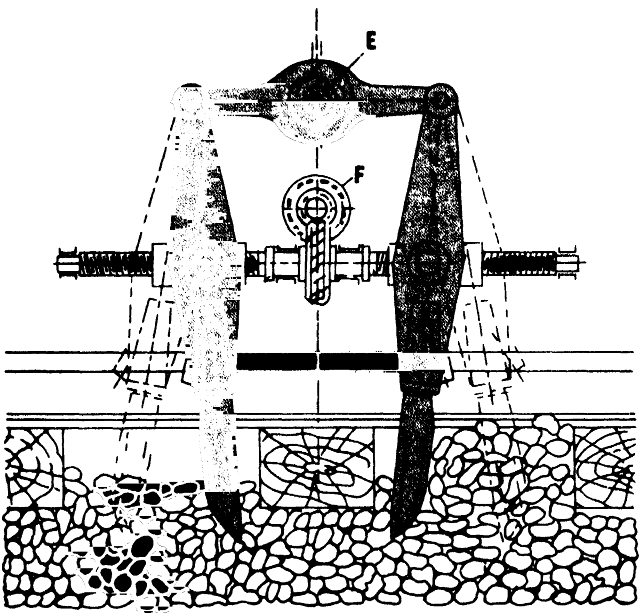


Fig. 1102*e*

1103. Periodical overhaul and through packing or surfacing

The surface of a track deteriorates with use, sometimes rapidly and perceptibly, due to various adverse factors and at other times, slowly and imperceptibly. Spot surfacing, described in the previous paragraph, is not enough to maintain the track in good fettle. A general periodical overhaul of the surface is desirable. The ballast is packed uniformly under each sleeper, the surface is brought to the correct level, and invisible surface defects are automatically remedied. Some track inspectors are averse to

periodical overhaul of track, particularly if the running over it is fairly good. The arguments put forward usually are that if a track is running fairly well, any attempt at overhaul merely disturbs well bedded sleepers and that there is insufficient time for the men to do this work, as their time is taken up by spot packing and miscellaneous works. Such an argument is fallacious because the track, unless it is periodically overhauled, becomes dead, namely, looses its resiliency and produces hard riding. Again, if the track is periodically overhauled, it does not require as much spot surfacing as is necessary with a track which is maintained without such periodic work.

The periodical overhaul consists essentially of through packing, coupled with slight lifting, aligning, screening, ballasting and tightening of all fittings. In through packing, every sleeper is packed as described in para 1102 whether it appears to need packing or not. By this means fresh ballast is packed under the sleeper and the resiliency of the track is maintained. When doing through packing, it is often desirable to lift the track, be it as little as a fraction of an inch. If through packing is done at long intervals, lifts of 2″ or more are necessary. The ballast under the sleeper gets gradually pounded to dust and a certain quantity of ballast also sinks in the formation, the quantity thus lost depending on the nature of the soil in the formation. The track has therefore a tendency to be gradually depressed and periodic lifting overcomes this tendency. Additional ballast has to be added when giving the track a lift.

Through packing should be carried out continuously from one end of each gang section; through packing of isolated stretches should be discouraged. This however should not prevent through packing of a bad stretch at any time with a view to improving it. The results of through packing, as also of spot packing, depend entirely on the interest the men take in their work, and the mere fact that a track has been through packed is not sufficient guarantee that it will ride well. As a check on the work done, the inspecting staff should observe the effects on the track of a passing train. In a properly packed road, no sleeper should sink, however slightly, under the wheels. Inspection by travelling on an engine also reveals whether the track has been packed properly.

When heavy lifts of 3″ or more are made in a track, the full lift should not be given in one operation, but the track should be raised in two or more stages. A gradual slope of about 1″ per rail length should be left at the end of the lifted length when stopping work for the day. Again, full lift should not be given on one rail followed by a similar lift on the opposite rail, as a

heavy lift on one rail has a tendency of throwing the track out of alignment. After heavy lifting, the track should be aligned, that is, brought back to its correct position, as it is likely to have moved slightly during lifting operations. The sleepers should then be thoroughly packed. A second packing after a short interval is not only desirable but sometimes very necessary. Lifting of track should not be done unless there is sufficient ballast for the lift, otherwise there is very little ballast left for the shoulders and the lateral stability of the track is affected. For normal lifts, the usual method is to lift the track on the existing ballast and unload additional ballast as soon as possible and make up the shoulders. For heavy lift, it is necessary to unload part of the required quantity of ballast before lifting. The balance of the supply is unloaded after lifting. Special care in levering or jacking up the track is necessary when lifting a pot sleeper road otherwise the gauge is affected as the connection between the pots and tie bars is not very rigid. It is also good practice to break the old ballast core formed under each pot and repack. The track at bridge approaches should be made exactly level with that on the bridge to allow trains to travel smoothly on and off the bridge. A few days after a length of track has been lifted, it is advantageous to go over this length and pick up any low spots which may have developed.

1104. Shovel packing

Shovel packing is a method of spot surfacing adopted extensively in Britain and is applicable to track with sleepers with flat-bottom surfaces. In this method, very small stone chips, about $\frac{1}{4}''$ to $\frac{3}{8}''$ average size, are spread under the sleepers. The thickness of the layer depends on the amount by which each individual sleeper is to be lifted to remove low spots or sags from the track. Ballast at the shoulder is removed from the end of the sleeper to the level of the bottom of sleeper. The track is raised with track jacks sufficiently to allow a long trowel with a layer of chips to be inserted between the top of the ballast and the bottom of the raised sleeper. The required quantity of chips is loaded on a trowel, the loaded trowel inserted in the space and the chips spread evenly with a deft movement of the hand. The size of the trowel varies, but a common size is $36'' \times 5\frac{1}{2}''$ to $6''$. The track is lowered after the chips have been spread and dressing of the shoulder ballast completes the operation. The success of shovel packing depends on the skill in judging the quantity of chips required. Sighting boards are used for bringing the track to the correct level.

Shovel packing has not been done in India, except on an experimental basis, and some experiments carried out by the author on a length of track requiring constant attention were found to be reasonably successful. Shovel packing has many advantages for spot packing of track over the method described in para 1102. The sleeper bed is not disturbed and the progress is over five times that of ordinary beater packing.

An improvement on this method is termed *measured shovel packing*. The amount by which each sleeper is to be lifted is carefully ascertained and a measured quantity of stone chips is spread under the sleeper. Boning or sighting rods are used over a depressed length or sag and the depression at each sleeper is measured with an adjustable graded rod. The invisible voids under the sleepers are also measured with *voidmeters*. A void-meter consists of a spring pointer, the other end of which is heavily loaded and rests on the end of a sleeper. The pointer with its scale, is attached to a rod which is fixed in the ballast, close to the end of the sleeper. The pointer moves when a train depresses the sleeper and with it, the heavy end of the pointer. A subsidiary spring pointer is moved by the loaded pointer and remains in place after the loaded pointer returns to its normal position when the sleeper springs up after a train has passed. The distance between the two pointers is the measure of the void. The amount of sag and void are added together and an appropriate quantity of chips are spread with the trowel under each sleeper.

It is claimed for measured shovel packing that track surface remains satisfactory twice as long as with unmeasured shovel packing.

Shovel packing however requires a well settled ballast and should not be used on new tracks or on track renewal.

1105. Surfacing on curves

The outer rail on a curved track is kept a little higher than the inner rail, in order to counteract the centrifugal force. Although the reason for introducing superelevation is to eliminate the horizontal thrust due to this centrifugal force, it is not possible to remove this completely, as the centrifugal force varies with the speed. As it is not possible to run every train round a particular curve at a predetermined speed or to vary the superelevation for every train, a certain amount of horizontal thrust is exerted on the outer rail, if the speed for which the curve is superelevated is exceeded. If, on the other hand, the speed is less than that

for which the superelevation is fixed, a greater portion of the load has to be carried by the inner rail, instead of each rail carrying half the load. The track on a curve is consequently subjected to greater stresses and therefore deteriorates more rapidly than on a straight. Maintenance of the correct superelevation is essential as any variation in superelevation results, not only in very uncomfortable riding but also in varying horizontal thrust on the outer rail with consequent deterioration in alignment. The checking and correcting of cross level on a curve is therefore even more important than on a straight. The superelevation is constant over the body of the curve, but at each end of the curve this superelevation has to be gradually reduced to zero. This is done over the transition portion of the curve. *Transition curves* enable trains to enter curves smoothly and eliminate the jerk that otherwise is felt at the tangent point. The gradually changing superelevation over the transition is checked and corrected with the help of reference pillars at short intervals and similar to those mentioned in para 1102.

1106. Surface defects and remedies

(*1*) *High joints*—These are caused by overpacking of joint sleepers or sinkage of intermediate sleepers, possibly due to insufficient attention being given to them. The effect of high joints is to produce motion in a vehicle similar to that felt on a galloping horse, although on a very much smaller scale. Such joints are therefore sometimes termed *riding joints*. Remedy lies in either lifting and packing the intermediate sleepers to the level of the joint sleepers, or in lowering the joint sleepers by breaking the ballast core under these and repacking to correct level.

(*2*) *Blowing joints*—The term is applied to a joint, the surroundings of which are coated with a fine layer of dust. This is a definite indication that the joint sleepers are not only bedded on loose ballast and badly need packing, but also that the ballast is full of dirt or pulverised stone. As the loose sleeper is relieved of each passing wheel load, it draws up, by suction, powdered ballast and dust from the formation. This is particularly the case when the layer of ballast between the sleeper and the formation is thin. The dust is blown out when the next wheel load depresses the loose sleeper and this makes the surroundings dusty. The situation is aggravated by battered rail ends, weak sleepers and wide expansion gaps.

Remedy lies in cleaning the dirty ballast, providing sufficient additional ballast, if it is insufficient, thorough packing of the joint sleepers and tightening the joint fittings. Improvements of

battered rail ends, as explained in para 213, and reduction of expansion gaps may also be necessary. A temporary relief may be obtained by pouring water on the ballast, after packing, in order to lay the dust, but this does not give lasting results.

(*3*) *Pumping joints*—In rainy weather, a blowing joint is converted into a pumping joint. Mud splashes all round the joint under moving loads and the joint deteriorates rapidly. The immediate cause of pumping joints is bad drainage. If the ballast is dirty, it does not allow water to drain away and water collects in the pocket of loose ballast formed under the joint. Improvement in drainage is essential, in addition to the other remedies indicated for blowing joints. If water is always present in some cuttings due to seepage, special steps may have to be taken. Deeper side drains with sides pitched with stone, or perforated pipes under the track, or a blanket of ashes under the ballast, may be advisable. As a temporary remedy, the ballast may be dug away from the ends of the sleepers down to the bottom of the pocket and the water drained from it. This is sometimes called *bleeding of sleepers.*

(*4*) *Variation in rail tilt*—Rails are tilted at an angle of 1 in 20 to correspond with the coning of wheels. When the rails have correct tilt, namely when the sleepers are correctly adzed in case of wooden sleepers, the wheels move centrally over the rail. If one rail has a smaller tilt, a larger diameter of the coned wheel comes in contact with the rail as the inner edge of rail is slightly higher. As both wheels are rigidly fixed to the axle each wheel cannot run on a different diameter. The result is that the wheels move sideways till diameters on the wheels are equalised. It can be easily realised that if there is variation in the tilt of the rail, there is considerable side to side movement of the wheels, and therefore of the vehicles, and the result is poor riding.

(*5*) *Hogged or crippled rails*—In para 210 mention was made of the battering of rail ends resulting in the rails becoming crippled or hogged. Firm packing of joint sleepers goes a long way in preventing the rails from getting hogged. As a temporary measure, the joint sleepers of hogged rails are packed higher than the intermediate sleepers. The ends of rails do not however remain in the slightly raised position for any length of time. Liners or shims between rails and fishplates (*vide* para 405), also help. Hogged rails can however be permanently rectified by one of the following three methods: (*5.1*) cropping, (*5.2*) welding, and (*5.3*) dehogging.

(*5.1*) *Cropping:* A short length at each end of the rail is cut off, thus removing the vertically bent portions from the

rails, new holes are drilled for fishbolts and the shortened rails used again. In this process, the rails have to be removed from the track for cutting and drilling holes and the shortened rails have to be relaid. This involves considerable expense and loss of a certain length of rails, both of which are avoided in the other two methods. In America, a method of cropping rails at site has been tried. The rails are cut and drilled at site with portable machines and pulled back to fit the adjoining cut rail and the gaps are filled with additional cut rails previously distributed along the track at appropriate distances.

(*5.2*) *Welding :* The building up of rail ends with welding has been explained in para 219.

(*5.3*) *Dehogging :* The vertical bend in the rail is removed by bending the rails in the opposite direction with the help of a dehogging machine. Details of dehogging work are given in para 1511.

(*6*) *Heaved track* — Certain types of soil, such as black cotton soil, expand with moisture and, in rainy weather, banks made of such soil cause trouble. A layer or blanket of ashes or moorum, between the ballast and the soil, reduces this undesirable feature. Heaving of track is a much more serious problem and occurs in areas subjected to frost. As packing cannot be done when the track is frozen, the low places are raised by inserting wooden packings between the rails and sleepers. These have to be removed when it thaws and the track is then packed in the normal way.

(*7*) *Centre bound sleepers*—Under rolling wheel loads, the ballast is pressed down under the rail seats more than at the centre of the sleepers due to the loads being greater under the rail seats. If slight lifts are not given under the rail seats periodically to eliminate the depressions, the sleepers instead of being supported firmly at the rail seats are found to be better supported at the centre. This causes rocking of trains and the sleepers are said to be centre bound. Centre binding can be easily removed by loosening the consolidated ballast at the centre of the sleeper. When through packing a track it is good practice to break the hard core by working the sharp end of the beater under the centre of the sleeper. Centre binding does not occur where a shallow central depression or drain is left in the ballast section.

1107. Packing on ballast other than stone

For packing ashes, sand, moorum or earth, wooden beaters and shovels should be used in preference to steel beaters. The ballast must be kept clear of the foot of rails and the section shown in Fig. 604*a* should be adopted. The slope from the centre of the track to the shoulder should be continuous and depressions or pockets formed under the rails, whilst packing, should be removed by dressing. Difficulty is often experienced in packing the track on earth or moorum ballast in the rainy season, as the material gets sodden and sticky. The levering up of the track for packing becomes most difficult, as the lever fulcrum keeps on sinking in the formation, which has also become soft. These conditions apply particularly to newly laid tracks, where the spreading of stone ballast is postponed until the formation has consolidated sufficiently. Long poles or bullies, about five inches in diameter and 20 feet long, have been used successfully as levers in lieu of crowbars. Fulcrums made of wooden blocks 24″ × 10″ × 5″ and 12″ × 10″ × 5″ cut from unserviceable wooden sleepers are used with the bully levers. Where the fulcrum blocks also sink in the soft soil,

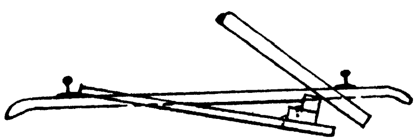


Fig. 1107

fulcrum boards, consisting of three pieces of 5″ diameter bullies five feet long and strapped together, are laid below the fulcrum block as follows. In the space between adjoining sleepers, a slight depression is made below the foot of the rail and one end of the fulcrum board is placed in this depression. The other end of the board is laid on the inner foot of the opposite rail (*vide* Fig. 1107). A fulcrum block is placed on the depressed end of the board, a bully is introduced between the foot of the rail and the block, and the rail is then levered up. If the board and block sink, a second block is introduced on top of the first block. The blocks have a tendency to slide on the board, and two dogspikes are fixed in the board to prevent this. The placing of one end of the board on the foot of the rail results in better distribution of the fulcrum load and prevents the board in its turn from sinking into the formation.

1108. Irregularities in alignment and their correction

When a vehicle passes over a track, the wheels have a tendency, due to various causes, to move slightly from side to side. Wheel flanges exert side thrusts on the rails and if these thrusts

are of any magnitude, the track is pushed slightly out of position or alignment. If the alignment of the track is allowed to become irregular, the surface of the track is affected. The gauge also suffers, as the rails are subjected to heavy blows and severe side pressures, since the wheels tend to resist displacement. Several other factors tend to disturb the alignment of a track. If cross levels of the track are not perfect, the load of the vehicle, instead of being equally divided over the two rails, increases on the lower rail and this has a tendency to push the track out of position. The alignment on curves suffers due to variation in the centrifugal force, caused by variable superelevation. Formation, made of poor soil, is a serious factor in throwing out the alignment due to sinking or sliding of the track. Insufficient ballast for taking up the lateral thrusts from the wheels is also a common cause of this defect. If the defect in alignment is not attended to promptly, further distortion occurs at a rapidly increasing rate. This is particularly the case with tracks on which speeds of trains are high and where loads of vehicles are heavy.

Fortunately, it is not difficult to bring the track back to its correct position, on straight lengths. About six to eight men, or more if considerable shift is required, are provided with lining bars or crowbars, which are heavy steel bars about five to six feet long. The bars are jumped at an angle into the ballast under the rail and are made to bear against the foot of the rail. The men heave or jerk the bars in unison at a command from the mate. The lining bars must be fixed at a steep angle against the foot of the rail otherwise there is a tendency for the track to be lifted instead of being pushed sideways. When bars come into the vertical position, due to the movement of the track, fresh purchase is obtained on the bars by jumping them again at a slight angle and the operation is repeated till the track has reached the desired position. For straightening the track, it is sufficient to obtain a straight line on one rail. The other rail will then automatically be in a straight line, unless the gauge is irregular. The man directing the operations, who usually is the section mate, stands at a distance of at least three rail lengths (over 100′) from the portion to be aligned. The irregularity in line of the rail is easily seen by him from this distance and the slewing operations are regulated so that a perfect line is obtained. It is advisable for the man directing the aligning operations to stand with the sun behind him as better sighting is thus possible. The lining men first work against the central portion of the bulge or kink in the track. Quarter points of the bulge are then tackled and the intermediate portions are dealt with subsequently, the men working up and down the irregular track until a dead straight line is obtained. When the shift is

considerable, it is advantageous to move the track a fraction of the shift throughout its length and repeat the process till the final position is reached. If the full shift is attempted in one operation, considerable force is required, the track has a tendency to spring back and fishplates are liable to be slightly bent. In order to reduce the resistance offered by the track, when being pushed sideways, it is advisable, particularly when the shift is considerable, to remove the ballast from the forward end of each sleeper. With hollow sleepers, such as the steel troughs, the removal of the ballast from the forward end is essential, otherwise not only is the resistance offered considerable, but the forward end of the sleeper also gets lifted before it moves forward and the surface of the track is thereby disturbed. It is also necessary, if the core is considerably consolidated, to loosen the core at the back end of the sleeper to allow the sleeper to move. With pot sleepers, it is essential to loosen the core, if the shift is heavy. As a rule, trough sleepers are more difficult to align than wooden sleepers but on the other hand they are less liable to move out of position.

After aligning a length of track, it is absolutely necessary to through pack the length, otherwise it will not only move out of the corrected position but will also give very poor riding. Aligning, for this reason, should always precede surfacing and if a track happens to be aligned after packing, repacking is essential.

In case of track with long welded rails realigning should be avoided at temperatures greater than that at which the rails were laid, or destressed.

No mention has so far been made of the realignment of curves. The track on a curve, however well it may be maintained, does not retain its correct alignment for any considerable length of time due to the tremendous horizontal thrusts exerted on the rails by the centrifugal force. The condition is aggravated with higher speeds, as the centrifugal force varies as the square of the speed. Minor adjustments may be carried out by the method described for straight portions of track, any obvious irregularity in the smooth curve being picked out by eye. The sighting rail on curves should be the outer or higher rail. Aligning a curve by eye, however, gives only approximate results and cannot be considered satisfactory for present-day needs. Correct alignment by eye of a curve throughout its length is not possible and a curve which may appear smooth and regular to the eye may have serious defects. The methods of correcting the alignment of curves is described in para 1313. After the corrections are worked out, rail pegs are fixed by the side of the track and at a fixed distance from it. These pegs are fixed usually at every rail length and the amount of

superelevation at each peg is also indicated by cutting a notch in the peg. The section mates should align the track from these pegs and raise the outer rail above the inner rail according to the notch indication on the pegs. Any attempt at aligning by eye, except very obvious isolated kinks in between pegs, should be severely deprecated.

1109. Variations in gauge and re-gauging

The gauge, namely the distance between the inner edges of the two rails, must be kept uniform, otherwise the riding qualities of the track are adversely affected. As the tread of the wheels are coned, if the gauge gets slightly wider, the diameter in contact with the rail increases on one wheel and for the same amount of rotation, this wheel tends to cover a greater distance than the opposite wheel. But as the two wheels are rigidly connected to the axle, relative motion between the two wheels is not possible and skidding of one or both wheels takes place. This, in turn, causes the wheels to hunt or nose from side to side. Again when the gauge is wide, the wheels have a tendency to move from side to side and the wheel flanges may even strike the two rails alternately. The results of such movements are lurching and rough-riding. The surface and alignment are adversely affected and the situation is further aggravated.

Tracks originally laid to uniform gauge, become irregular after the lapse of time. This is due, in case of wooden sleepers, to the spikes crushing the timber fibres and widening the spike holes on account of side thrusts from wheel flanges. In case of steel sleepers with keys, the gauge is altered, if the keys are not kept tight or if the fittings are worn. With pot or plate sleepers with tie bar connections, the gauge, in addition to the variation due to loose or worn fittings, is easily affected due to insufficient attention to packing. For instance, if the ballast on the outside of the pots is loose the pots have a tendency to tilt outward, resulting in slack gauge.

In France, when there is slight variation in gauge, the maximum gauge variation between two adjoining sleepers is limited to 2 mm. (1/12").

The gauge on a wooden sleeper track is corrected as follows. First one rail is aligned ~~by eye~~ as already described. If the gauge is very irregular, all the inside spikes and about half the number of outside spikes of the rail to be aligned are removed and the spikes holes are plugged. The remaining outside spikes are loosened. The track gauge is fixed on the rail over each sleeper, and spikes redriven. When fixing the track gauge, it is essential to see that it is held square, otherwise correct gauge will not be

obtained. If the rails are worn and have burrs along the inner edge, the gauging should not be done against such burrs. An easy method of avoiding this is to have a notch at the junction of the vertical with the horizontal arm of the gauge, in which any burrs can be housed. To ensure that the gauge is held square, one end of it is moved from side to side whilst the other end is held against the opposite rail. The arc produced by such a movement clearly indicates the correct position.

In case of steel sleepers, the adjustment of gauge is very simple if the sleepers are fitted with four keys. All that is necessary is to loosen the keys and drive the outer key if the gauge is wide, or the inner key if it is tight. When the sleepers have only two keys each, liners made of hoop iron of varying thickness are necessary, if correct gauge is to be obtained. If the keys are on the inside of the rails, the gauge can be widened by driving them further. If the gauge is to be tightened, liners are necessary on the outside of the rails. With keys on the outside of the rails, the position is reversed.

Before regauging a pot or plate sleeper road, the track should be thoroughly packed. Slight adjustments can be made in the gauge with such sleepers by packing the outside of the sleepers more than the inside if the gauge is to be tightened and *vice versa*. This is possible as the tie-bars are not rigid enough to prevent slight tilting of the pots or plates. This method, except for the slightest occasional correction, is not recommended as the cant of the rail is altered and uneven wear takes place on the rails.

Uniformity in gauge, even though it may not be absolutely exact, should be aimed at, as variation in gauge is most harmful. As a rule, a slightly tight gauge gives better running than a slightly slack gauge, as it prevents lateral play of the wheels.

In America, special devices, such as gauge rods and rail braces, are used at intervals on wooden sleeper tracks. These help to keep the rails to gauge and relieve the dogspikes of some of the very great lateral thrusts. A *gauge rod* is simply a rod with one fixed jaw and one movable jaw which is adjusted with a nut. The jaws grip the outer edge of the foot of each rail and prevent the rails from spreading. A *rail brace* has four movable jaws on a fully screwed rod and these jaws, by gripping the foot of each rail, prevent the gauge either from widening or from tightening.

1110. Kinks—buckling

When the ends of adjoining rails move slightly out of position, shoulders or kinks are formed. The causes of kinks are several.

They may be due to loose packing at joints, defect in gauge or defect in cross levels at joints. Kinks can be noticed easily and corrected by aligning the joints and packing. Kinks, if allowed to remain, develop rapidly, and cause unpleasant jerks in vehicles passing over them. Kinks at joints develop more easily on curves than on straights and a badly maintained curve may have a series of kinks. Slight kinks also appear at places other than the joints. These are mostly due to uneven wear of rail head on account of incorrect camber or due to defect in gauge or in alignment.

If expansion of rails is prevented in hot weather, due to either the fishplates being bolted so tight that the rails cannot slip or the expansion gaps being insufficient, the force of expansion throws the track out of position and a *buckle* is formed. Buckles in tracks have caused serious derailments. The necessity for lubricating the contact surfaces of fishplates and rails at regular intervals, say once a year or once in two years, is obvious. It is equally necessary to see that the fishbolts are not tightened so much as to prevent expansion or contraction of rails.

Rails also have a tendency to creep, or move bodily in one or other direction. This tendency has been explained in para 1210. One of the effects of creep is to bunch the rails together, closing the expansion gaps in short or long stretches and fully opening the gaps in other stretches. Unless the closed gaps are re-opened, buckling of the track is likely in hot weather. Buckling takes place at some weak spot in the track, for instance where there is insufficient ballast or where the track has been disturbed by lifting, heavy sleeper renewal, etc. The necessity of watching and adjusting closed expansion gaps during hot weather cannot be emphasized too strongly. The safety of trains is involved and the greatest attention has to be paid to this point. Prevention or reduction of creep, as a permanent remedy, is dealt with in para 1212. A temporary measure, which is dealt with in para 1211, is the pulling back or adjustment of rails to reinstate the correct expansion gaps. If there is insufficient time or labour to effect this over a long length, short or cut rails may be introduced at the worst places so that expansion gaps may be made available by adjusting a few rails only.

Track subject to heavy creep should not be opened out to any extent in the hottest part of the day in hot weather, as any loosening in the grip of the ballast helps in forming a buckle. For the same reason, lifting of the track subject to heavy creep should be avoided in the middle of the day in hot weather.

1111. Maintenance of ballast and boxing

It is necessary to have sufficient ballast to form a cushion for the track, to permit its efficient drainage and to hold the track from lateral movement.

Formerly ballast was heaped up on the shoulders and sometimes in the inter-rail space, almost upto the top of the rails, under the mistaken idea that the more ballast there is in the track, the more capable is the track of withstanding lateral thrusts and maintaining perfect alignment. Experiments have shown that the lateral strength of a track depends chiefly on the sleeper spacing and the value of the grip they have in the ballast either through friction or otherwise.

The lateral strength of a track is not appreciably increased by heaping up ballast at the ends of sleepers. The cost of the additional ballast and the extra work entailed in removing this ballast when any work has to be done on the track is an unnecessary expense.

On completion of packing, the ballast which is scattered during the packing is gathered and put back in order to restore the profile of the ballast layer. A common practice in boxing is to pull up scattered ballast with shovels or phowras. This results in the earth and weeds from the formation being pulled up with the ballast and fouling the ballast. The correct method is to pull up the ballast with ballast forks. The toes as well as the shoulders of the ballast should be made up to form straight lines. This gives the track a finished appearance. Untidy tracks, even if correct in alignment and level, appear poorly maintained. The psychological effect on workmen of a job neatly done is considerable and neat boxing should be insisted on, not however at the expense of poor surface or alignment. Considerable loss of ballast also occurs due to its being scattered, if it is not neatly boxed. Ballast has to be added from time to time as some of it is lost by crushing and due to being pressed down in the formation. The method of replenishing ballast is given in para 605. When further ballast is added to the track, the addition should be so regulated that excess ballast does not occur in any place. If excess ballast is found anywhere on the track it should not be allowed to remain scattered, either on the top or on the slopes of the formation, but should be used up by either making the shoulders slightly wider or kept in neat stacks by the side of the track.

1112. Cleaning track and weeding

In rainy weather, weeds grow, not only on the slopes of the formation but also on the cess as well as in the ballast. Vegetation on bank and cutting slopes is an advantage as the more profuse it is, the less chances there are of the slopes being scoured by heavy rain. The presence of vegetation on the cess and particularly in the ballast is, on the other hand, a source of trouble. The cess must be kept clear of vegetation to allow rain water to escape freely from the track. Weeds grow in ballast which is full of earth and rubbish. They prevent drainage as the roots tend to bind together the material and as the weeds increase rapidly. Constant removal is necessary during the rains. Pulling weeds up by the roots is much more effective than cutting, as growth is not checked by cutting. Again, it is far better to remove the weeds before they develop sufficiently to form seeds, as the seeds get scattered and increase the growth considerably. Eradication of weeds by burning or by spraying suitable chemicals is extensively carried out in America. Special wagons fitted with sprays are slowly drawn over the track and the sprayed chemicals destroy the weeds. Hand spraying of chemicals has been experimented with in India but has not achieved marked success. If the ballast is clean, weeds cannot grow as there is no earth or rubbish available from which the roots can derive sustenance.

1113. Screening ballast

Under the constant hammering action of wheel loads, ballast gets pulverised, even the hardest material being reduced in time to dust. The powdered material fills up the interstices in the ballast. Ashes dropped from locomotives, dust sucked up from the formation, blowing dust and sand, and growth of vegetation in dirty ballast augment this process and the ballast layer gradually becomes impervious. Drainage of the track is thereby affected and the track deteriorates rapidly during the rains. The condition is aggravated by pockets of clean ballast being formed under rail seats, where ballast is constantly packed, and such pockets being surrounded by impervious dirty ballast which prevents such pockets from being drained.

The ballast under the sleepers also gradually consolidates into earth concrete and the resiliency of the track is affected.

To remedy these defects, the ballast is cleaned by screening it. Screening may be divided into two different categories, one which only improves the drainage and the resiliency of the track, and

the other in which a fresh road bed is obtained. Additional or make-up ballast is required in both cases, but far more in the second than in the first case.

Screening for drainage purposes is carried out on some railways as part of routine work of section gangs. Ballast above the dotted line only in Fig. 603*b* is screened, leaving an unscreened ridge at the centre to act as a water divide. Ballast in the cribs, namely the space between sleepers, only is screened and the consolidated cores under the sleepers are not touched, except for breaking the core under the centre of the sleepers to remove centre binding. Such screening improves the track considerably, particularly if there is soft stone or gravel ballast in the track. The actual operation is carried out as follows. The surface ballast, which is usually fairly clean, is pulled out with ballast forks from one crib and deposited in the adjoining screened crib. The caked and dirty ballast is then loosened with picks and thrown on to frames about $5' \times 4'$ with 3" mesh expanded metal. These frames are propped at an angle on the cess with suitable supports and are usually placed parallel to the track. When a basketful of dirty ballast is thrown on this screen, the dust and small particles go through the mesh and fall on the bank slope where they help in building up the bank. When screening is done in cuttings, this dust and small particles fall in the side drains and have to be removed. The screenings are dumped usually on the top of the cuttings, but such dumps should be kept a sufficient distance from the top edge of the cutting to prevent them being washed down the cutting slope in rain. Clean ballast rolls down in front of the screen and is collected for filling the adjoining screened crib and the process is repeated. As the section of the ballast layer is decreased by screening, additional ballast is added to make good the shortage. About half a rail length, namely about 18 to 21 feet of track, can be screened by one man in a day by this method. Another method of screening is to remove, with shovels or phowras and baskets, the ballast from the cribs and shoulders and dump it on the cess. Then put it back in its original place with ballast forks. This method is wasteful as large quantities of suitable stone are left in the heaps on the cess from which the ballast is removed by forks for reuse.

Some maintenance men prefer not to screen the shoulder on the outer side of a curved track, as a consolidated shoulder is considered to have greater resistance to lateral thrust than a shoulder of loose ballast. This practice cannot be recommended.

Where through screening, namely the resurfacing type, is undertaken in a track which has not been screened for many years,

the quantity of ballast may be depleted considerably through screening and restrictions in speed may have to be imposed till sufficient make-up ballast is provided. To avoid this contingency, it is advisable to distribute, on one side of the track, part of the make-up ballast and to use this ballast as the screening progresses. The sequence of operations for through screening is as follows. Ballast from the cribs and shoulders is removed and thrown on the screens. The cores under the sleepers are then broken and the material screened. The entire layer of ballast down to the formation is removed and screened. It is desirable to remove this layer in such a way as to have a ridge at the centre of the formation, with gentle slopes on either side. In case of double or multiple tracks, the ridge should be kept at the centre of the formation width and not at the centre of each track. The depth, to which screening is done under each track on a double or multiple line, is governed by the slope from the central ridge to the shoulder of the formation. Clean ballast, together with fresh ballast, is placed in the track and the sleepers are then packed. The packing of sleepers has to be repeated before the track is sufficiently consolidated. Through screening is usually coupled with complete resurfacing, including pulling back of rails, if they have crept, squaring and respacing of sleepers, if they have been pulled askew or out of position due to creep. Further details of through screening are given in para 1508.

Some permanent way men are not in favour of screening a track, their argument being that screening disturbs the track structure and instead of improving the running, makes it worse. Screening undoubtedly disturbs the track structure but unless screening is done periodically, the track gradually deteriorates, unnecessary effort is required in spot surfacing damage occurs to the track materials, and the track loses its resiliency. Screening requires strict supervision and the subsequent packing has to be done most thoroughly. Any shortcoming in this packing results in poor riding and the blame is laid on screening instead of on indifferent packing. The author considers screening absolutely necessary for keeping a track in good fettle. The interval at which screening for drainage purposes should be done, depends on the type of ballast, and the nature of the soil in the formation. On some railways it is done every fourth year. Each section gang screens one mile of its length every year and if the section length is three miles, screening is repeated every fourth year. No fixed period can be laid down for through screening. It depends very much on the condition of the track and its riding qualities.

The following deductions from American tests indicate one more reason for keeping the ballast clean. It is reckoned that

only about 10% of the wave action set up in the track by moving loads is absorbed by the rails and sleepers and the remainder is taken up by the ballast. The depression under moving loads in a track with cinder ballast was found to be 2½ times that in a track with hard firm stone ballast. Considerable energy of the locomotive is therefore wasted when travelling over a cinder ballasted track.

Hard stone ballast loses its resistance to sleeper thrust when it is permeated with dust and water, and depressions increase. It is therefore desirable to screen ballast. If screening is done at the shoulders and in the sleeper spaces only, the results are considered to be about 60% effective.

American practice is to clean the ballast on the main lines every three to five years, on branch lines every five to eight years and on important lines in yards every one to three years. The screening there is done to the bottom of the ballast and the quantity of make-up ballast required is specified as 15% to 25% of the full section. Screening in that country is done with special ballast cleaning machines. They are self-contained units which dig up ballast with clamshell buckets, throw it on an inclined vibrated screen and redeposit screened ballast on the track, retaining the rubbish in a box. A simpler machine has a revolving screen. Ballast is dug out by men and thrown into a hopper, from where it finds its way to the revolving screen, and the screened ballast falls along the shoulder, the rubbish being collected in a box, or thrown clear

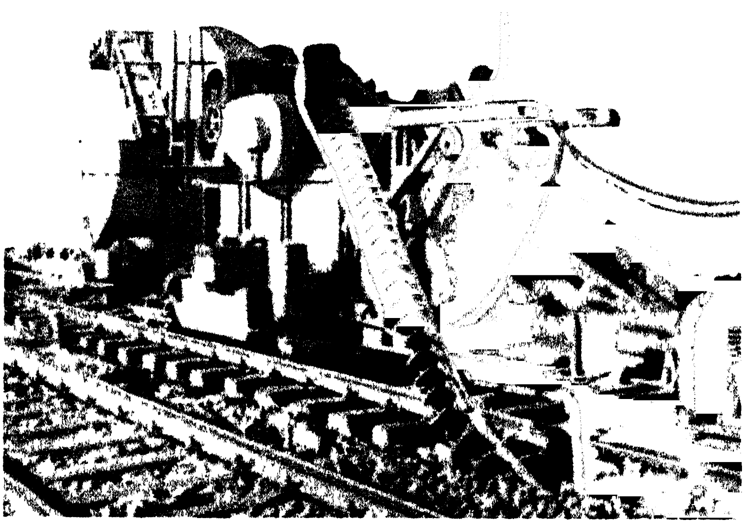


Fig. 1113

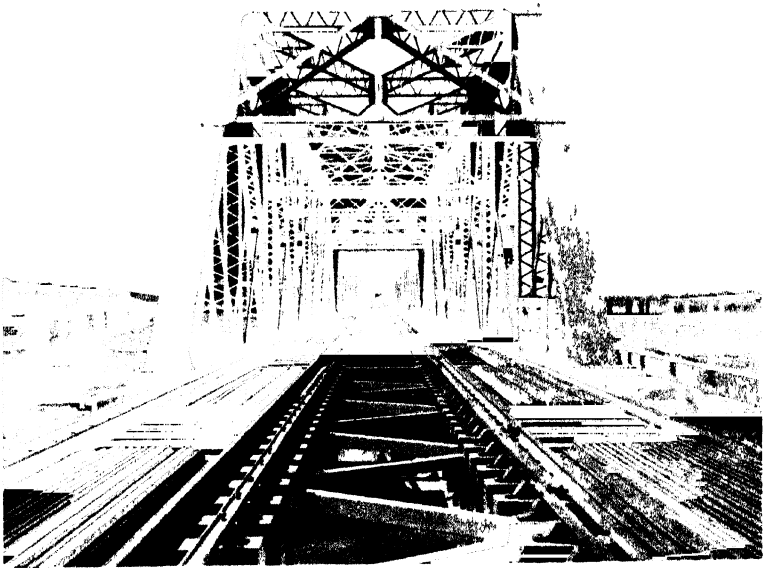
of the track with the help of a belt conveyor. A composite screening machine (Matisa) is illustrated in Fig. 1113. It is estimated that a ballast cleaning machine can do the work of 80 men. In Britain, washing of ballast which is badly fouled by clay, ashes, etc. has been tried. Large quantities of water are used with the ballast whilst it is agitated and screened.

A simple but effective equipment, known as a *Ballast Drag*, which has been used successfully in Britain, might be adopted with advantage in India.

It consists of a steel frame with a steel plate 10′-6″×8′ (for 4′-8½″ gauge track) to which 8″ long tines and a V-shaped plough are fixed to the lower surface. The upper surface is provided with three slightly curved skids.

The drag is introduced beneath the sleepers after jacking up the track. It is attached to a spreader bar which in turn is fixed with wire ropes to a locomotive. The drag is pulled by the locomotive at a low speed of 3 m.p.h. The skids force up the track and the tines scarify the ballast. The movement of the drag brings the shoulder ballast under the track and the plough diverts some of the ballast from the track centre. The result is a lift of about 3″ and scarified ballast in the track.

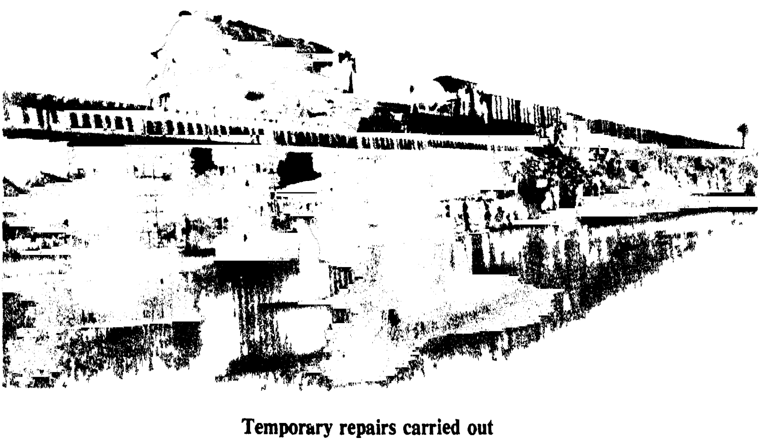
Provision of additional ballast and subsequent packing result in a track with renewed ballast. The drag is also used as a preliminary operation before cleaning the ballast with a Matisa ballast cleaner.



A large girder bridge with two tracks. The old bridge is seen on the left

Tracks distorted and scoured by storm and flood

Broad gauge WG Locomotive for goods train (details are in Appendices 16 2 and 16 3)



Temporary repairs carried out

Maintenance of Track—*continued*

1201. Drainage

ONE of the essentials of a good track is good drainage. In dry areas, drainage of track may not be as important as in wet areas, but neglect of drainage even in dry areas may cause serious trouble in a heavy shower. One of the essentials of good drainage is clean ballast. The second essential is the rapid disposal of rain water. There is not much difficulty on banks regarding the second point but in cuttings, side drains have to be provided to drain away rain water as explained in para 607. Even on banks, if the shoulder of the cess is higher than the level at the toe of ballast, a certain amount of water will remain under the ballast. When repairs to banks are carried out, care should be taken to see that

the cess shoulders are not made unduly high. If existing cess shoulders are high, they should either be trimmed level with the ballast toe or cuts should be made through them to drain away any water held up by the high shoulders. The inner edge of a side drain is kept a few inches from the toe of the ballast. If the drain is kept too close to the toe of the ballast, it will get gradually filled with ballast. On the other hand, the outer edge of the drain should not undercut the slope of the cutting. Side drains silt up gradually, and if the soil of the cutting is loose, silting is very rapid. The silt has to be removed, if the drains are to function properly. In removing the silt, care should be taken to provide a continuous grade along the bottom of the drain. If there are errors in the grade, pockets of water form in the low places. It is also good practice to start silt removal from the outfall of the drain and work up to the higher end. If the reverse procedure is followed, there is a possibility of the outfall being made too deep for the natural drainage of the surrounding land. As tracks in cuttings are usually on a grade, the rails form a good guide, and the bottom of the drain is kept a fixed distance below rail level throughout the cutting. When drains are completely choked with silt, the edges of the drain should be demarcated with strings stretched between pegs to avoid irregular edges. Some gangmen have a habit of throwing the silt on the cutting slope, instead of depositing it at the top of and a little away from the edge of the cutting. This is wasted labour, as the first shower brings down all the silt deposited on the slope. Side drains which have to carry large quantities of water or drains with a constant flow, due to seepage, are sometimes pitched. The pitching renders their maintenance easier.

In order to prevent water from the surrounding land pouring into a cutting and transforming the cutting into a drain, drains are also cut along the top edges of the cutting and a few feet, usually about 5′, from the edges. Water from the surrounding area is caught in these *catchwater drains* and led away without being allowed to enter the cutting. Catchwater drains are usually of a size larger than side drains and they require to be kept clear of silt just as much as side drains. As they are not easily visible from the track, they should not be allowed to suffer from neglect. If water pours into the cutting from the top of the slope or if slips occur in a cutting, the cause may invariably be traced to accumulation of water on top of the cutting due to a neglected catchwater drain.

Side drains in some cuttings get choked with silt at every shower. Remedy in such cases lies in cutting back the slope to a gentler grade or in turfing the slope. Clods of turf dug from the

neighbouring ground laid on the slope and pressed down produce excellent results. If the outfalls of side drains are heavily eroded, boulder filling stops further trouble.

On double line sections, where the layer of ballast for each track is separate, the space between the near shoulders of the two ballast sections appears in the form of a shallow trench. The water from this trench is drained through the ballast of either track, if the ballast is clean. Even with clean ballast, water is not drained rapidly, and it is advisable to have cross drains at intervals through one or the other of the two tracks. Such cross drains should never be cut under rail joints, but at the centre of the rails. If the track is on a steep grade, earth cross bunds should be built across the trench, immediately below each cross drain, to prevent the water in the trench gradually increasing in volume and velocity, resulting in quantities of ballast being washed away.

Drainage in station yards has to be carefully planned. The best arrangement is to have a side slope in the formation and to effect drainage by a series of cross drains. Longitudinal drains between tracks, although common, are a source of inconvenience to the yard staff, as they have to walk between the tracks for shunting and other operations.

Wet spots or waterlogged beds are sometimes found either in banks or in cuttings, well below the surface of the formation, and the stability of the track is considerably affected in such places. There are several ways of dealing with such spots. One method is to cut a deep drain across the track till the soft spot is reached and fill it with rubble. Water seeps through such a rubble drain. A better arrangement is to introduce earthenware pipes with open joints or perforated corrugated iron pipes. In case of cuttings, the pipe has to be continued parallel to the track and below formation level until the outfall is reached. Pockets of soft soil have also been stabilised by injecting cement grout under pressure. When there are stretches of track on soil which holds water and does not drain effectively, or when the levels of the country prevent effective drainage, such as in low-lying marshy country, a blanket of ashes or moorum, or of rubble is laid below the track ballast. Reinforced concrete slabs have also been used both in India and abroad, but are very expensive. In rainy season, a bank made of poor soil, if not properly drained, sometimes gets saturated with water and portions of the bank slip down. The immediate remedy is to erect a breast wall of unserviceable sleepers, by driving the sleepers along the toe of the bank, and to fill up the cavity with a light material like ashes. Permanent remedy lies in properly draining the bank, as already explained.

1202. Maintenance of track on bridges and approaches of girder bridges

At the junction of a girder bridge with a bank, there is a considerable change in the resiliency of the track. The track on a girder bridge rests directly on girders, which yield far less under load than the track on the adjoining bank. The level of the track on a girder bridge cannot vary whilst that on the approach is liable to alteration, and unless special attention is paid to rail levels at the approaches, bumps will be felt. Usually the bump is due to the approach having sunk, but on black cotton soil, in rainy weather, the track may have heaved up slightly due to the swelling of such soil. Longitudinal timbers about 15′ long are sometimes used in pairs under the rails at bridge approaches. One end of the longitudinal timber is laid on the end of the girder and the other end is laid on the ballast. The two timbers are joined together suitably with timber bracings or with rods and pipes, the pipes acting as separators. Such *run-off frames* eliminate the sudden difference in level which might possibly occur at the junction of the bridge and the bank.

Sleepers used on bridges are spaced so that a derailed wheel cannot fall through and in case of large bridges, the sleepers are prevented from being pushed out of position by special guard rails described in para 510(*c*). The sleepers are held to girder flanges with hookbolts, the hook end of the bolt gripping the girder flange and the bolt being threaded through the sleeper. Hookbolts which hold the sleepers to the girders, are liable to turn on account of vibration and, due to this turning their grip on the girder flange is reduced. Hookbolts should therefore be adjusted before tightening. A mark is often found on the top of the bolt to indicate the position of the hook.

In order to clear the rivet heads, sleepers are notched on the under-side. Notching is a slow process and such notches prevent a sleeper from one location being used in another location without cutting fresh notches. A more effective way is to cut grooves at right angles to the length of the sleeper, the distance between the grooves being made equal to the pitch of the rivets. Sleepers of varying thickness have to be used on girders to make allowances for the thickness of the flange cover plates. Girders are normally cambered, that is, they have a slightly hogged surface. Formerly the practice was to reduce the depth of the sleepers gradually towards the centre of the span, so that the surface of the track remained level in spite of the camber in the girders. This practice is now changed. The amount of camber is usually equal to the amount by which the girder deflects under load, so that when the

girder is fully loaded, it becomes straight. Sleepers are not now reduced for camber, since if they are reduced, a sag occurs in the track when the girder is deflected under load. The track on a long bridge, with several large spans, does not appear level but exhibits a series of hogs and sags, the highest point of each hog being at the centre of each span. This is due to the camber of the girders and when a train passes over the bridge, the hogs are levelled out due to the deflection of the girders.

Rain water has a tendency to lodge between the contact surfaces of the girder and sleepers and when the girders are painted these small areas are left untouched. It is therefore necessary to periodically move the sleepers and repaint the contact surfaces to prevent corrosion. If the sleepers are grooved instead of being notched, to clear rivet heads, they can be easily moved for painting the contact surfaces.

1203. Maintenance of level crossings

Where a road crosses a railway track, the surface of the road is kept at rail level and grooves are left in the road surface along the inner edges of the rails for the wheel flanges. These grooves are provided by means of guard rails. Guard rails are usually spiked to wooden sleepers and if the track is laid with trough, pot or plate sleepers, each level crossing is especially provided with wooden sleepers unless some special fittings are used for attaching the guard rail direct to the running rail (*vide* para 510*d*).

Unless the whole surface is disturbed, a level crossing cannot be packed. This cannot be done often for obvious reasons, hence special care is needed in packing a level crossing. Once a year the level crossing is opened out and the rails and fittings are tarred, to prevent corrosion. A badly packed crossing is easily noticed as the road metal adjoining the rails gets loose. On level crossings with heavy traffic, wooden or bitumen surfaces are often provided. The wooden surface is obtained with old sleepers, shaped and fitted to a frame underneath. In such cases the foundation may consist of a layer of concrete, so that there are very little chances of the track being disturbed and packing being required.

Approaches of level crossings also need frequent attention, as unpleasant jerks are felt if the approaches have sunk.

1204. Maintenance and renewal of rails

A 90-lb. 42′ rail weighs a little over half a ton and careless handling is liable to damage it. For instance, rails should not be

unloaded by throwing them from the wagons. They should be slid down ramps, made of a couple of unserviceable rails. Rails are turned over on their side by introducing tommy bars in a bolt hole at each end and levering it over. Rails may be brought to the correct position by sliding them or lifting them bodily either by hand or with rail tongs (Fig. 1204), two men being required for each tong. Rails should also not be left in an untidy heap, as a rail near the bottom of such a heap may be bent by the weight above. Rails are stacked in layers, the rails in alternate layers being turned upside down, for nesting snugly in the space between the heads of rails in the lower layer.

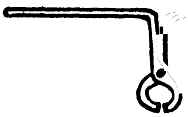


Fig. 1204

Due to one of several causes indicated in para 217, some rails have to be removed before others, and if the number of rails to be renewed is small, spot renewal is carried out. Spot renewal is not recommended, particularly if the heads of the rails in the track are worn. When an isolated new rail is put in, the table of the new rail is higher than that of the adjoining worn rail and its ends are therefore damaged by passing wheels. A better procedure is to lay a continuous length of new rails and use the rails thus released for spot renewals. Although this means doubling renewal work, it is well worth the extra cost and trouble.

For spot renewals, where traffic is heavy and the time for renewal limited, two out of four fishbolts at each end are removed and the remaining oiled if necessary. The spikes from alternate sleepers are also removed. The new rail is kept alongside the rail to be renewed. Immediately after a train has passed, the remaining fishbolts and spikes are removed and the rail pushed into the inter-rail space. The spike holes are plugged if the spikes are found loose. The new rail is levered into position, connected to the adjoining rails and spiked in three or four places, after holding it to correct gauge with crowbars. The remaining spikes are then put in, fresh holes being made with augers where spikes holes were plugged. It is good practice to tighten the fishbolts a second time. The same procedure is followed with trough, pot or plate sleepers, keys and distance pieces being dealt with instead of spikes. With bull-headed rails, the existing rail has to be lifted bodily out of the chairs after the chair keys are removed, and the new rail has similarly to be lifted and placed in the chairs. The keys are then driven home. When renewing a continuous length of rails in heavy traffic, a number of rails are joined together with fish-plates and bolts and kept ready alongside the rails to be renewed.

This saves the time required for fixing fishplates and bolts. This procedure is however inapplicable to bull-headed rails.

Battered ends necessitate more renewals than any other cause apart from renewals due to wear on curves. The life of rails can therefore be lengthened considerably if low joints are avoided by keeping them well packed and by providing correct expansion gaps, as indicated in para 213.

Rails on curves, particularly on sharp curves, have to be renewed sooner than on straight lengths and the expedients for prolonging the life of rails on curves have been discussed in paras 213 and 214. When check rails are attached to the inner rail of sharp curves, the side wear on these check rails may reach such proportions that the flange of the wheel on the outer rail may start wearing the side of the outer rail due to the space between the inner rail and check rail becoming excessive. Renewal or turning of check rails is then necessary.

It is difficult to specify a figure for the life of a rail, as this depends on so many factors such as intensity of traffic, location on straight or curves, standard of maintenance, nature of soil, atmosphere, chemical composition of rails, etc. For estimating purposes in India, a life of 45 years is assumed.

If a rail is found broken or cracked in a track, a sleeper should be placed immediately under the crack or fracture until the rail is renewed. Trains can then be passed at reduced speed. A detailed report in a special form is invariably made, to enable the cause of the failure to be detected. The various types of rail failures have been described in para 218. The fractured portion is sometimes smeared with grease and pieces are cut from the rail on either side of the fracture. The greasing permits investigation without the fractured surfaces being fouled with dirt or rust, and the cut pieces are easy to handle and transport.

If a kink or slight elbow is found in a rail, the gauge is affected and the only way of removing the kink is to apply a jim-crow at the kink.

Corrosion of rails is heavy in yards due to rubbish falling from trains, and ashes in contact with rails. Oiling the foot and web of rails with discarded lubricating oil or with heavy black oil, reduces such corrosion. The oil is easily applied with a swab. In tracks close to the sea, a similar remedy may be applied. Oil sprayers fixed on special vehicles are used in America for this purpose.

The necessity for bending and cutting rails is explained in paras 207 and 208. Bending of a large number of rails may be done

in a machine at a depot, but bending of a large number is seldom necessary and difficulties arise in transporting bent rails. A rail may be bent in the field as follows. The rail is placed on a platform usually of sleepers, on which the curve, to which the rail is to be bent, is marked out. A jim-crow is then applied starting from one end and working through the length of the rail. One arm of the jim-crow is applied at the end of the rail and a slight pinch given with the screw. The arm is then moved to the first position of the screw and another pinch given. The operation is repeated till the other end of the rail is reached.

The neatest cut on a rail is obtained with rail saws. These may be power-driven or hand-operated, the latter taking considerable time in cutting. Rails can also be broken by other methods. The rail is chisel marked at the point to be cut and a jim-crow is applied with the screw at the chisel mark. A break occurs after a certain amount of tightening of the screw. If the cut is required very near the end of a rail, another rail is fished to it, to enable both arms of the jim-crow to have a purchase, but as the fishplates get bent in the process only unserviceable plates should be used. Rails can be cut even without a jim-crow and a knowledge of such methods may come in handy in an emergency. A chisel cut is made all round and the rail placed on blocks across the sleepers in the inter-rail space. A number of crowbars are pressed down on the rail near the chisel mark, one end of each crowbar being wedged under one of the running rails and a hard chisel cut made. This breaks the rail at the chisel mark. There are a few variations of this method, in one case a long piece of rail is dropped on the chisel mark, after placing the rail to be cut across two track rails. In another variation, the length of the rail on one side of the chisel cut is spiked to sleepers and the free end is bent with crowbars and a hard chisel cut made at the same time.

1205. Maintenance and renewal of sleepers

The care which must be exercised with wooden, steel and cast iron sleepers is indicated in paras 308 to 310. When packing sleepers, the beaters or tie tampers must not be allowed to hit the sleeper, otherwise the sleeper is liable to be damaged. This is particularly the case with cast iron and concrete sleepers. When laying wooden sleepers, the heart side must be kept on the under-side of the sleeper to prevent increased absorption of moisture and consequent decay. Sleepers are also apt to be pulled into a slightly skew position due to creep. The gauge is affected when this happens. Skew sleepers must not be squared by hammering them. When

squaring sleepers they should be pushed with crowbars by jumping the working end of the crowbar into the ballast close to the sleeper, making this end act as a fulcrum and levering the sleeper into position. Pulling a wooden sleeper with the help of a beater, by driving the pointed end into it, damages the sleeper. Fittings must be fixed with care in all sleepers. If spike holes are not bored in wooden sleepers in the correct position or if the spikes are not driven correctly, the spike does not grip the rail satisfactorily or the fibres of the sleeper are damaged, due to side thrust on spikes incorrectly fixed. When driving a spike, the first few strokes should be light, for setting the spike in correct position; similarly the last few strokes should also be light to prevent damage to the spike after the head comes in contact with the foot of the rail. The man should stand on the same side of the rail as the spike, otherwise it is likely to be driven at an angle. If keys are driven unduly hard into the lugs of a steel sleeper, the lugs are apt to be torn. If fittings do not fit snugly in cast iron sleepers, cracks are likely to appear. Due to vibration of trains, the fittings get loose and must be constantly tightened. Neglect of this work would not only wear out the sleeper and fittings and give bad running but in extreme cases, may render the track unsafe. The remedies to be adopted when a spike looses its grip in a wooden sleeper are explained in para 502. With steel sleepers having clips and bolts for fastening rails, the bolts must be oiled and turned periodically, say once in two years, to prevent the nuts from *freezing*.

Holes for spikes must be bored right through the sleeper to prevent the spike from damaging the unbored depth. Through boring also prevents accumulation of moisture with the resulting decay. All discarded spike holes must be plugged to prevent collection of moisture. The useful life of an untreated wooden sleeper is considered to be about 15 years in India. The life of a steel sleeper may be taken to be about 35 years and that of a cast iron sleeper is over 40 years, although the sleeper would probably be renewed before this period due to other causes such as wear of fittings, increased axle loads, etc.

Renewal of sleepers can be conveniently divided into *spot renewal* and *through renewal*. Spot renewal is carried out as follows. New sleepers are first distributed opposite the sleepers to be renewed. Ballast is removed with picks all round the sleeper to a depth a little below the bottom of the sleeper. The spikes or fittings are removed and the loose sleeper pulled out from under the rails. The reverse process is followed for inserting the new sleeper, which is then levered up with crowbars for spiking or for fixing fittings. The new sleeper is thoroughly packed. Jacking up

of rails does not facilitate the extraction and insertion of sleepers as loose ballast falls in the sleeper cavity. Slight levering up of the track, however, after the ballast round the sleeper has been removed facilitates extraction. Sometimes the ballast is removed from one side of the sleeper only, the sleeper is driven sideways into this cleared space or trench and pulled out, after the spikes are drawn. Adjacent sleepers should not be renewed at the same time, as there will be insufficient support if a train happens to pass during the process of renewal. If many sleepers are to be renewed in each rail length, the trains should be slowed down.

In America, the renewal of wooden sleepers is done by cutting the sleeper into pieces at site with portable power saws, the cuts being made in the inter-rail space near the foot of each rail. The central piece is picked up and the end pieces pulled out after fittings are removed. The new sleeper is then inserted in the trench left by the old sleeper.

For through renewals, the rails are removed, ballast taken out from the cribs, old sleepers picked up, the remaining ballast spread evenly, new sleepers laid, the rails linked and the crib ballast put back. Thorough packing is then done. Very often through renewal of sleepers is combined with ballast screening and addition of ballast, so that a fresh resilient track is obtained. If the rails are renewed on existing sleepers, the sleepers, if they are of wood, are readzed. This is done in America with portable power adzes without removing the sleepers from their position.

It is useful to remember that even old rails of light section can provide a good track if the sleepers and ballast are in good condition.

As sleeper renewals are heavy compared to rail renewals, it is essential to see that only the bad sleepers are removed. Elaborate procedure for marking bad sleepers is followed on various railways. Sleepers which require immediate renewal and those which need renewal in the near future, say in a year, are marked differently and renewals carried out accordingly. The marking is repeated every year and an estimate of the next year's requirements formed after the sleepers have been marked. The marks also provide a means of easy check to ensure that good sleepers are not inadvertently renewed. When wooden sleepers are put in the track, they should invariably be dated, as explained in para 308.

Released sleepers have considerable use. As it is not wise to leave wooden sleepers in a main line until they become totally unserviceable, many of the sleepers removed from main lines are

used in branch lines or sidings, the better ones being used in branch lines. Again, wooden sleepers are released which may no longer be fit to serve as sleepers but from parts of which good timber can be obtained for structural work. If a sleeper is made unfit due to enlarged spike holes it may still be used in sidings by shifting the position of the rail seat slightly. The sleeper will not be symmetrical in the track but this does not matter in a siding. In the worst condition, a wooden sleeper is fit for firewood. Some of the wooden and steel sleepers rendered unserviceable for broad gauge are cut down for use on metre and narrow gauges. Conversion, for smaller gauges, of used steel sleepers is carried out by pressing down the existing lugs if the sleepers are of the lug type, cutting the sleeper to the requisite size and punching fresh lugs. If the steel sleepers are of the loose jaw or clip bolt type, fresh holes are made for the jaws or bolts.

As cast iron sleepers normally become unserviceable when they are cracked or broken, they cannot be reused, but the broken pieces can be melted and excellent cast iron obtained.

As the cost of sleeper renewal is heavy, every effort should be made to prolong the life of the sleeper by good maintenance. Damage to untreated wooden sleepers by termites, such as white ants, must be guarded against. On a line carrying heavy traffic, frequent vibrations prevent heavy encroachments by termites but in light traffic lines, runs of white ants are found and these must be constantly removed. The day line guard or keyman must be given strict instructions about their removal. Wooden sleepers are liable to be burnt by red hot coal or ashes dropping from engines. This occurs particularly in dry weather but such occurrences are not frequent and fortunately such fires do not spread to adjoining sleepers. Renewals should be done first at those patches where bad sleepers exist in large numbers. If there are insufficient sleepers for necessary renewals, alternate bad sleepers should be renewed.

1206. Maintenance of fittings

The most important track fittings are fishplates and fishbolts. It is essential to lubricate the contact surfaces of the fishplates periodically. This period is normally 12 months. It is equally necessary to oil the fishbolts at the same time. Any thick oil, it may even be waste oil, serves the purpose. The lubricant used for the fishplates varies with each railway but consists usually of a graphite and grease compound.

If the plates are not lubricated, they prevent free expansion and contraction of rails. If the bolts are not oiled, the nuts *freeze* on the bolts and cannot be turned.

Due to vibration caused by passing trains, the fishbolts get loose, resulting in loose fishplates which give rise to low joints, crippled rails and damaged fishplates. Bolts should therefore be constantly tightened. A certain amount of wear also takes place at the contact surfaces of the fishplates, but the need for tightening the bolts on account of this wear is neglible compared to the tightening required on account of vibration. If the contact surfaces of fishplates are worn to such an extent that the plates grip the rail web, the fishplates must be renewed, otherwise the rail ends will not have proper support and will be damaged.

The remedies for worn fishplates have been given in para 405. Accurately tapered shims will be found very useful for improving bad joints.

A fishplate is sometimes found cracked or broken in the track. If another fishplate is not handy, a sleeper should be fixed under the joint temporarily. A detailed report on the fracture is necessary to ascertain the cause of the failure.

When fishbolts are removed from the track for any reason, the serviceable ones should be sorted from those which have become useless and the threads should be oiled. The bolts should be carefully stored. The same remarks, apart from the oiling, apply to all other track fittings. Large quantities of used materials can be reconditioned and put to use in sidings and other unimportant places and quantities thus reclaimed by a little care and attention are surprisingly large.

Dogspikes can be easily removed with claw bars. Their removal from confined spaces, such as at points and crossings, is effected by means of a small scissors-shaped link. The claw bar is threaded through the loop of this piece and the spike is levered up. Further details of maintenance of fittings are given in paras 502, 507 and 508.

1207. Programme work

Track maintenance needs careful planning, over short or long periods, if the track is to be kept in good fettle and if arrears of work are not to be piled up. There are some trackmen who consider that planning maintenance work is an unnecessary elaboration. This is a greatly mistaken idea and if good results are desired, efficient methods must be employed and planning the

work ahead is one of these methods. Planning may be done by the Inspectors or the general outline of the work, required to be done from month to month, may be laid down by the Engineers. The first method is suitable with highly efficient and keen Inspectors, as it gives them a certain latitude to deal with special local conditions which cannot be covered by a general programme applicable to the whole railway. The author however prefers the second method, in which an outline of the programme is laid down for all Inspectors and their assistants to follow. If any deviation is required, due to any special local condition, alterations in the general programme can be easily made with the consent of the Engineer. This method ensures a uniform standard of maintenance.

A convenient time unit for programme work is the week. A certain number of days must be left in each week for spot packing, as and when required and for doing other routine work. The number of spot packing days will vary with the condition of the track but should not normally exceed two, and at most, three days. If considerable time is employed in spot packing, the other essential works are given less time, the track deteriorates further and more spot packing is necessary, and this constitutes a vicious circle which must be avoided. If the condition of the track has deteriorated to such an extent that spot packing cannot be confined to two or three days' work, it is better to employ additional labour, but this should seldom be necessary unless the track is badly neglected.

The track deteriorates during the rainy season and the section gang is kept busy during these months spot packing, keeping drains clean, weeding the track and through packing bad lengths. The annual track programme may therefore start conveniently in October or as soon as the rains are over. In areas which are subject to the north-east monsoon, the programme may start early in the year. The first item of the programme should be a general rapid overhaul. This consists of packing of all joints and centres of rails, removing weeds if any, boxing the ballast, cleaning cess and side drains and, in general, tidying up the track. This work may last from six to eight weeks. A quick overhaul of points and crossings, particularly those in main lines, at the same time, is desirable. This should be followed by renewal of sleepers and fittings, about four weeks being devoted to this work. During the same period, pulling back required should be done and if the track has sleepers with clip bolts, such clip bolts should be oiled. Through packing, including screening of a certain length, and surfacing should then be undertaken systematically from one end of each section. This can be continued for five months and this

period will be sufficient for completing the work, with a margin for other incidental works. Lubrication of fishplates and bolts should be carried out in the hot months, say March and early April. Just before the rains break, the side and catchwater drains should be attended to. The above should be taken only as a guide, alterations being made where necessary. A track maintenance programme chart is given in Appendix 14.

1208. Track imprest

Apart from the materials used for renewals in the track, a small number of rails, sleepers and fittings are permanently kept at selected places for immediate renewal of broken rails, etc. These materials are sometimes known as Track Imprest and are in the nature of an insurance against unforeseen breakages. They are to be used only in an emergency, and any item withdrawn for use must be replaced as soon as possible.

1209. Task per man-day

The following work can be normally done by one man in one day on broad-gauge track and the list is given as a guide. Proportionately more work can be done on metre and narrow gauges.

(*1*) Spot packing and dressing : 15 to 20 sleepers.

(*2*) Through packing : One rail length (36′).

(*3*) Screening for drainage : Half rail length (18′).

(*4*) Lubricating fishplates and bolts : 20 to 30 joints.

(*5*) Adzing and boring 2 holes only in wooden sleepers : 40 to 50 per carpenter and helper, provided restacking of sleepers is done by additional men.

(*6*) Stacking sleepers with a little lead : about 200.

(*7*) Dating wooden sleepers : 70 to 100 per carpenter and helper.

Other data will be found in paras 1004, 1211, 1503 and 1508.

1210. Creep: cause and effect

Creep is the longitudinal movement of rails in a track. Creep is common to all railway tracks, but varies considerably in magnitude, the rail in some places moving several inches in a month,

whilst in other locations the movement may be negligible. Creep is attributed principally to:

(*1*) Wave motion set up in the resilient track by a moving train. Portions of rail immediately under the wheels of a train are depressed slightly due to the load on the wheels. The rails under a train have therefore a slightly wavy outline. As the wheels move, the depressions move with them, the previously depressed portions springing back to their original level. This wave motion tends to move the rail forward with the train. The pitch and depth of the waves is governed by the condition of formation, the stiffness of track, the weight of rails, the spacing of the sleepers, the wheel base of vehicles, the quality and quantity of ballast, the condition of drainage and the standard of maintenance. Increased stiffness of track, stability of soil in formation and angular ballast which interlocks well, reduce wave motion and therefore creep.

(*2*) Expansion and contraction of rails due to temperature, which again is influenced by the range of temperature, location of track in exposed or shady surroundings, etc.

(*3*) Starting, accelerating, slowing down or stopping of a train. When a train is starting or accelerating, the backward thrust of the engine wheels tends to push the rails backwards. When it is slowing down or coming to a stop, the braking effect tends to push the rails forward.

These are the principal, but by no means the only causes of creep. Following are some of the items governing the direction and magnitude of creep:—

(*1*) Alignment of track : Creep is found to be greater on curves than on straights.

(*2*) Grade of track : Rails normally creep in the direction of the down grade, although creep in the reverse direction is not impossible.

(*3*) Direction of heaviest traffic : If loaded trains run in one direction and empty trains in the opposite direction, creep will usually be found in the direction of loaded trains.

Creep is not constant over any given period, nor does it vary at a uniform rate, nor does it continue in one direction, nor do both rails of the track creep an equal amount. In fact, the direction and extent of creep cannot be predicted. Both rails of a track

may creep in one direction, then perhaps both may reverse the direction of creep, or one rail may start creeping in a direction opposite to the other. Such variations may occur daily or may be seasonal.

The consequences of creep are several and serious, the most serious result being the buckling of the track. If unobserved and unattended, a buckle may easily derail a train with serious repercussions.

The more common results of creep are:—

(*1*) The sleepers are moved out of square and out of position and consequently the gauge and the alignment of the track are affected. Due to sleepers moving from their packed beds, the surface is also considerably affected and bad running results.

(*2*) Rail joints are opened out to their limit in some cases and considerable stresses are set up in the fishplates and bolts; the bolts sometimes break. The rails are also badly battered at the ends due to excessive gap. Joints in other places get jammed, preventing expansion.

(*3*) Points and crossings get distorted and it is very difficult to keep them to gauge or to correct alignment; the movement of the switches is made difficult and interlocking is thrown out of gear.

(*4*) If a rail is removed from the track for any purpose, it becomes very difficult to refix it. Either the gap after removal is found too short or too long due to creep.

1211. Pulling back

When rails have crept, causing disturbances in the track, noted above, they have to be adjusted or pulled back. The procedure is as follows. The track to be pulled back is inspected and the extent of pulling back necessary at various places is noted. The point from which to start is also determined; usually the starting point is at widely opened rail joints. Pulling back should be regulated in such a way that the rail joints are made central over the joint sleepers. It is not enough to merely obtain the necessary expansion gaps. The position of the joints relative to the sleepers and the position of one rail joint relative to the joint on the opposite rail must be maintained. Sometimes if a sufficient gap between rails is not conveniently obtained, a full rail is replaced by a shorter rail and a gap thus created. Fishbolts at one end of the rail

are loosened and those at the other end of the rail are removed. Sleeper fittings, whether spikes or keys, are loosened. The rail is then wedged backward by inserting a crowbar between adjacent rail ends. A liner of requisite thickness, to provide the correct expansion gap, is inserted at the joint towards which the rail is being pushed. Movement of the rail by wedging is not possible after the gap between the rails has gradually increased. Either pulling or pushing of the rail is then done. Pulling is done with a hook which is threaded through one of the bolt holes in the rail after removing the fishplates. The rail is then pulled by hauling on a rope attached to the hook. Pushing is done by inserting a short rod through the bolt hole and levering the rail forward with crowbars. The crowbars are jumped into the ballast at the slight angle and bear against the rod. After each rail has been pulled back as required, the fishplates are refixed. Sleepers, if they have moved out of position, are adjusted, and the sleeper fittings tightened. The track is then packed. Pulling back of rails may vary from a few inches to as much as a few feet. Cut pieces of varying lengths have to be kept handy so that if a train has to be passed whilst the work is in progress, an appropriate piece can temporarily fill the gap between the rails. Fishplates attached to the full rails at either end of the cut rail hold the latter in position. It is advisable to have large oval holes in the cut pieces so that they may match the holes in the fishplates easily. Cut pieces, if left in the track at the end of the day's work, must be securely held; they should never be left permanently in the track. The minimum length of a cut piece for fixing fishplates at either end is the length of the fishplate itself. The minimum length may be obtained, if necessary, by replacing a full length rail by a shorter rail, say a 36′ by a 33′ rail. Under no circumstances should two cut pieces be fixed adjoining each other as the lateral stiffness of the track is thereby considerably reduced. If it is absolutely necessary to have more than one cut piece in each rail of the track (and this can always be avoided by cutting appropriate lengths of rail and drilling on the spot) such cut pieces should be separated by at least one full rail between them. Trains are necessarily passed at slow speed for the duration of the operations.

Pulling back, rail by rail, is a slow process and is to be undertaken only if the pulling back is for short isolated lengths and the distance, through which the rails are pulled, is small. Where long lengths of track have to be pulled, a number of rails, varying from about four to six, are pulled together. The procedure is the same as above, but if the rails are moved with crowbars, short rods are inserted in every rail, a fishbolt being removed from each rail for this purpose.

Labour required for pulling back varies with the length to which the rails have to be pulled back, the number of sleepers which need adjusting, and the condition of packing of the track. Rails are sometimes pulled back without adjustment of sleepers. This may be satisfactory if the creep is small, if the sleepers are not much disturbed or if the pulling back is to be done in a hurry to avoid the possibility of buckling or further deterioration in track consequent on heavy creep. Adjustment of sleepers should however be carried out in the latter cases as soon after the rails have been pulled back as possible, otherwise the gauge will be found to vary considerably and undue wear of rails and deterioration of the alignment and surface of track will take place. For pulling back of rails only, about 40 to 50 men per mile are necessary. The best way of computing the number of men required for adjusting and packing sleepers is on the basis of six sleepers per man-day. These figures should be taken only as a guide and not as a fixed standard. Fewer men will be required if the sleepers need only slight adjustment or if they are of the type which can be moved easily, e.g., wooden sleepers. A mechanical appliance for pulling back consists of a screw with two clamps. One clamp is rigidly attached to one end of the screw and the other clamp slides on the screw. The clamps are attached to adjoining rails through bolt holes, the sliding clamp being attached to the rail that has to be pulled. By tightening a nut against the sliding clamp, the rail is pulled. The advantage of this device lies in the fact that several rails can be pulled at a time and fewer men are required than with the levering or pulling methods.

1212. Anchors or anti-creepers

After the rails have been pulled back, there is no guarantee that they will not creep again. In fact they start creeping immediately after pulling back and unless some device is used to prevent this, the work of pulling back has to be repeated sooner or later.

Creep is prevented or reduced by devices known as anchors or anti-creepers. Anchors are fastened to the foot of the rail and bear against the side of the sleepers. Some types of sleepers have fastenings which act as anchors due to the grip they have on the rails. Steel trough sleepers which have clip bolts for fastenings are an example. When the rails tend to creep, they have to drag the sleepers also through the ballast and the ballast offers sufficient resistance to prevent the creep of rails. Formerly devices for holding the track rigidly against longitudinal movement were fixed at intervals in the track. These were unsuccessful as all the creep accumulated at these isolated points and the danger of a

buckle in the track was increased due to the prevention of further movement of the rails at such points. Fishplates of the angle type were notched and spikes at joint sleepers were fixed so as to pass through such notches. These similarly proved unsuccessful due to the thrust being concentrated at joint sleepers and the sleepers being torn by the spikes. The solution to the problem lies in the distribution of the forces in the rails, caused by creep, against a large number of sleepers. The larger the number of sleepers, the better is the absorption of the forces by the sleepers, held in position, in turn, by the ballast. It is not necessary to fix anchors at every sleeper. On the other hand, if the number of anchors are insufficient to prevent creep, even though the creep may be reduced the sleepers, against which the anchors butt are moved out of position. Pulling back is therefore necessary on insufficiently anchored tracks. Due to the unpredictable variation in creep, the number of anchors necessary would vary at almost every few hundred feet. Such a distribution is not convenient and it is usual to have the same number of anchors per rail panel for considerable lengths. Six anchors per panel might constitute a good average for certain lengths whilst 10 may have to be the standard in other lengths and so on. The number of anchors may vary from a minimum of two to a maximum of twice the number of sleepers in the panel. A certain amount of pulling back sometimes becomes necessary even on well anchored tracks. Again, as the direction of creep is liable to be reversed, anchors have in some places to be fixed in both directions.

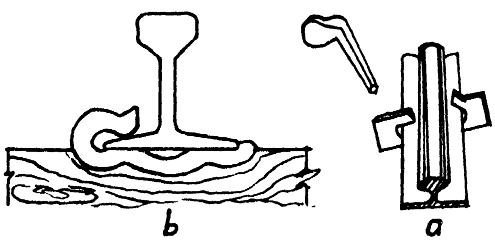


Fig. 1212

Anchors are fixed to rails (*1*) by wedging action (Fig. 1212*a*), (*2*) by clamping, or (*3*) by a spring grip (Fig. 1212*b*). There are several varieties of anchors based on these three types. The process of fixing the anchors, although different for each type, is very simple for all types.

The following points should be observed for the efficient maintenance of anchors :

(*1*) The anchors should butt against the sleepers otherwise they do not function.

(2) They should be distributed uniformly in each rail panel, so that the pressure against one sleeper is transmitted through the ballast in the cribs to the adjoining sleepers. Some railways bunch the anchors at the centre or ends of rails, but in the author's opinion, best results are not obtained with this arrangement.

(3) Defective anchors must be renewed to prevent accumulation of creep.

(4) There must be sufficient ballast in the sleeper cribs to prevent sleepers from being dragged with the rails. Ballast flush with the top of the sleepers is sufficient. Stone ballast, particularly hard angular stone ballast, has a better holding power than soft or round ballast such as shingle or ballast of material other than stone.

(5) Anchors should be fixed to good sound sleepers. If a sleeper which had an anchor fixed against it is renewed, the anchor should be refixed against the new sleeper. Positions of anchors should not be varied.

(6) Anchors, which depend on spring effect for their grip, must not be driven along a rail as this will destroy the spring.

(7) Fishplates must allow the rails to expand and contract freely. This is ensured by not overtightening the fishbolts and by keeping the contact surfaces well lubricated.

(8) It is good practice to increase the number of anchors at approaches to yards and in the yards as well, since creep seriously affects the alignment, gauge and position of points and crossings. Also, if the points are interlocked as is often the case, the interlocking mechanism is thrown out of gear and the points cannot be turned, resulting in detentions to trains.

Anchoring of long lengths of welded rails needs special attention. If rails are welded in short continuous lengths of, say, 168′ (4′×42′), the expansion gaps required would be theoretically about 1¼″. Such expansion gaps would be ruinous to the rails. As explained in para 204, with long rail lengths, the gap left for expansion is no more than that for a 42′ rail, but one has to cater for considerable locked up stresses due to prevention of expansion and contraction in the rails.

American practice, where long lengths of welded rails are in use, is to provide anchorage through bearing plates. The rails

are attached to the bearing plates with clip bolts and the bearing plates, in turn, are spiked to the sleepers. Spring clips are sometimes attached to bearing plates; elastic spikes which have a constant grip on the foot of the rail are also used.

The practice in some European countries with long welded rails is to anchor certain lengths at the two ends of the welded rails.

With long lengths of welded rails, the use of sleepers with fittings which prevent creep, e.g. steel trough sleepers with clips and bolts or with four keys, is recommended.

1213. Track work for high speeds

The energy of a moving vehicle varies as the square of the speed. If, therefore, the speed is increased from, say, 50 to 75 miles per hour, the energy increases from 50^2 to 75^2, namely from 2,500 to 5,625, or 2¼ times. The forces on the track are increased correspondingly and it will be easily realised that, with increased speed, increased attention to each detail of track maintenance is essential. Some of the essentials are:—

(*1*) The surface should be kept perfect.

(*2*) The alignment should be equally perfect.

(*3*) The gauge should be uniform and correct.

(*4*) Bad spots should be located as soon as they develop and should be promptly rectified.

(*5*) Curves should be given even more attention than straights. The centrifugal force on a curve varies as the square of the velocity and the outward thrust is proportionately increased with increased speeds. The lateral strength of the track should be adequate to withstand this thrust. As already mentioned, the lateral strength of a track depends mainly on the sleeper spacing and the grip of the sleeper in the ballast. Closer spacing and steel trough sleepers therefore increase lateral strength.

(*6*) Superelevation should be uniform over the circular curve and should vary uniformly over the transition portions. It should also be adequate for the average speed. In order to avoid undue load on the inner rail due to some trains moving at slower speeds than that for which the curve is superelevated, it is advisable to so regulate the speeds that the difference between the fastest and the slowest trains is not greater than 15 to 20 miles per hour.

(*7*) If screening or sleeper renewal has been done, the portions affected should be attended to repeatedly until thoroughly stabilised.

(*8*) Drainage should be adequate ; side drains should be clean ; cutting slopes must be at such an angle that drains are not silted at every shower. Soft formation should be stabilised with a blanket of ashes or moorum under the ballast and the ballast depth should be increased.

(*9*) If there is trouble from creep, adequate anchors are essential.

(*10*) The rails used should preferably be heat-treated and worn rail ends should be improved by welding, cropping or dehogging.

(*11*) Worn fishplates should be replaced, reconditioned or provided with suitable shims, and the fishing surfaces should be adequately lubricated.

(*12*) Fishbolts should be sufficiently tight, but not too tight to prevent expansion and contraction ; they should be well oiled.

(*13*) Sleepers should be correctly spaced and should be square to the rails. Closer spacing at the ends of rails, particularly at the joints, should be maintained.

1214. Fences—boundary marks—firelines

Fences are provided on either side of the track along the boundaries of the railway land to prevent trespass and to stop cattle from coming on the track. Fences also prevent encroachments on railway land. The fence usually consists of about five rows of galvanised seven strand wire threaded through posts of various designs, ranging from wrought iron flats to reinforced concrete or stone posts. Fencing wires must be kept taut and if broken or cut, should be promptly repaired. If loose wire is allowed to remain in the fence, the possibilities of theft are increased. Wire stretchers for pulling the wire taut must be freely used. It is not enough to pull the wires by hand. If a wire stretcher is not handy, a crowbar can be used as a lever for pulling by fixing one end in the ground. Considerable lengths of tracks are not provided with fencing. Fencing is however essential in the neighbourhood of populous areas, in the vicinity of all stations and near frequently used level crossings.

Whether fences are provided or not, the boundaries are marked with boundary marks, at short intervals, usually at distances of 500′ and at all corners in the boundary. The boundary marks may consist of built-up pillars, or slabs of stones, or pieces of rails embedded in concrete. It is an advantage to have them brightly coloured so that they may be easily located. The boundaries should be checked periodically. In some places, encroachments are not rare and one has to be on the alert for detecting such encroachments. It is worth while keeping the boundary marks as well as the fence free of tall grass and bushes, as it not only simplifies detection of encroachments but also gives the railway land a neat appearance.

There are certain areas where there is profuse growth of vegetation, including tall grass. In the dry weather, a spark from an engine may set this alight and if the fire spreads to the surrounding properties, claims for compensation are likely to arise. A strip about 5′ wide is therefore cleared along the boundary so that a fire may not spread. This work should normally be done before the advent of the hot season.

1215. Tidiness

Tidiness of the track, both in yards and outside yards, is not only desirable but necessary. Apart from the smart appearance which in itself is a very desirable feature, it has a very great psychological effect on the workmen. They learn to take pride in their work and produce better results. It is good practice to occasionally collect two or more gangs in a yard and tidy it up. A suitable occasion is pay day. Points and crossings may be attended to at the same time, all drains cleaned, the weeds removed from tracks, cess and platform, the ballast neatly dressed, renewed materials stacked and various other jobs carried out.

1216. Obstructions on track due to sand, snow, etc.

Where railway tracks pass through desert or semi-desert areas or even in a fertile area, in the vicinity of the sea or of sandy rivers, tracks are covered to varying depths by blowing sand. The sand must obviously be removed. The most handy but at the same time the almost laborious process is to remove the sand with phowras and baskets. Specially shaped ploughs pushed by an engine does the work quicker. The author once planted a hedge of cactus on the windward side on a short length of track close to the sea. Sand was found deposited on the windward side of the

hedge in a few days and the hedge acted as a barrier against the sand, preventing it from covering the track.

In some countries trouble is experienced with deposits of snow. Snow ploughs are used for clearing the snow. Special heaters are also employed at switches to melt the snow and permit free movement of the switches.

1217. Permanent way workshops

The Track Inspector has normally a carpenter and a blacksmith for carrying out various track works. The blacksmith is employed on cutting and bending rails, adjusting small fitting in points and crossings, drilling holes in rails, rousing bolts, carrying out repairs to tools, etc. The carpenter is used for adzing and boring wooden sleepers, repairing handles of tools and carrying out various miscellaneous works. A painter is shared between a number of sections. The painter is required for painting the mile and gradient posts, numbering telegraph posts (which form such convenient reference points), bridge and culvert numbers, and numerous other small painting jobs, e.g. painting of lamp posts, patch painting of girders, etc.

Heavy repair works are carried out in a central workshop in which heavy plant including that for maintenance of bridges is kept. The plant may consist of diverse items such as mobile cranes, welding sets, air compressors, pumps of various types, blocks and tackle, derricks, pile driving machines, boring machines, tie tampers, etc.

Maintenance of Track: Curves

1301. Curves: relation between degree, radius, versine chord and tangent

A CURVE is defined either by the radius or by its *degree*. The degree of a curve is the angle, formed by radii drawn at either end of a curve of length 100′. In Fig. 1301, a curve, or arc of curve, AB is 100′ and radii AD and DB are drawn, then the angle ADB gives the degree of curve. If the angle, for instance, is 1° then, since there are 360° subtended at the centre of a circle, the circumference of the circle is $360 \times 100 = 36{,}000$ feet. But as the circumference of a circle is also equal to $2\pi \times$ radius, the radius

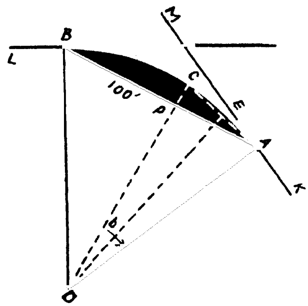


Fig 1301

of a 1° curve is $\frac{36000}{2\pi} = 5{,}730$ feet. This gives a simple relation between the degree and the radius of a curve. The circumference of a circle of a 3° curve is

$$360 \times \frac{100}{3}$$

since the angle ADB is 3°. The radius of a 3° curve is therefore

$$\frac{1}{3} \times 5{,}730 = 1{,}910 \text{ feet.}$$

Similarly the radius of a $\frac{1}{2}$° curve is

$$2 \times 5{,}730 = 11{,}460 \text{ feet.}$$

When any two points A and C on a curve are connected by a straight line AFC, this straight line is called a *chord.* If a radius DE is drawn so that it passes through the centre F of this chord AFC, the length FE is known as the *versine* say v and AF and FC are semi-chords c. It can be proved geometrically that versine FE is at right angles to chord AFC. It can also be proved that versine

$$v = \frac{(\text{chord AFC})^2}{8r} \text{ i.e. } \frac{C^2}{8r} \text{ or } \frac{AF^2}{2r} \text{ or } \frac{c^2}{2r}$$

where r is the radius of the curve AK and BL are the tangents of curve AB and are at right angles to radii AD and BD respectively.

1302. Methods of curve location

In Fig. 1301 when tangent KA and LB are produced they intersect at M, and the intersection angle NMA is equal to the central angle ADB The angle MAB formed between the tangent AM and chord AB is called the *Deflection angle*. The chord from end A to end B of the curve is known as the *Long Chord.* Curves may be located with or without the help of a theodolite. If a theodolite is used, it is fixed at the tangent point A and the curve is set out with the help of varying deflection angles. Two theodolites may be used for setting out, one at each tangent point. The curve may also be set out without a theodolite, by measuring offsets from the tangent AM or BN or by offsets from the long chord or by versines on the short chords.

Curves have sometimes to be set out for new sidings and the following method, by offsets from extended short chords, is the

most convenient for such work. In Fig. 1302, WX and YZ are tangents. XA, AB, BC are 100′ chords, and CY is a chord less than 100′. It can be proved that the offset B*b* or C*c* is very nearly equal to $\frac{\text{chord}^2}{\text{radius}}$. The offset A*a* is of half the value B*b* and the offset Y*y* is equal to $\frac{CY}{XA} \times$ offset A*a*.

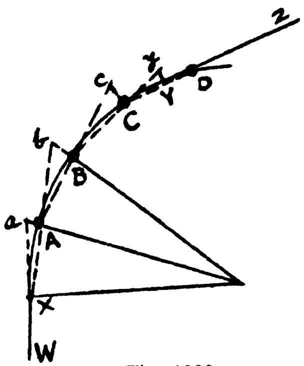


Fig. 1302

Having obtained the value of the offsets, the curve is set out as follows. A ranging rod is fixed at X and a 100′ tape is stretched from X to *a*, the latter point being kept in line with WX, by observing the rods at X and *a* from another rod erected at a convenient point W. From *a*, the offset *a*A is measured at right angles to X*a* and a ranging rod is fixed at A. The ranging rod from *a* is removed and is fixed at *b* with the help of a 100′ tape and the rods at X and A. Offset *b*B is measured at right angles to A*b* and the point B obtained. The operations are repeated till the tangent YZ is reached.

It must be understood that this is only an approximate method, and should not be used for locating curves on through tracks; for this, a theodolite is essential.

1303. Limiting radius or limiting degree of curve

The smallest radius or the largest degree, to which a railway curve may be laid, depends on two factors. The first of these factors is the length of the *wheel base* of a vehicle. The wheel base is the distance between two adjoining axles of a vehicle held rigidly together by the frame of the vehicle. If the degree of a curve is large for the length of the wheel base which forms a chord on the curve, the vehicle does not run freely round the curve and is liable to derail. The length of wheel base is however comparatively small, particularly in the case of vehicles with bogies. The second factor, limiting the sharpness of a curve, is increased operating and maintenance costs. Greater effort is required by engines in hauling vehicles over sharp curves than on straights, and the wear on rails, as well as vehicles, is very great. In case of through tracks, however, the limiting factor is the superelevation

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on curves. It will be seen in para 1305 that the full amount of superelevation (which increases with the degree of curvature) has to be limited, so that the stability of vehicles standing on the curved track may not be affected. Superelevation also varies as the square of the speed and due to the above limit imposed on superelevation, the radius of the curve has to be kept much larger on through tracks, where high speeds prevail, than on sidings where speed is very low. In India, curves on through tracks are limited to the following degrees : broad gauge to 10°, metre gauge to 16°, and narrow gauge to 40°. The maximum degree of curve is sometimes determined by the maximum superelevation permissible with speeds of about 90 miles per hour without the possibility of the stability of vehicles, standing on such curves being affected.

1304. Compound and reverse curves

It is sometimes necessary to have a curve formed of two or more simple curves of different degrees. It is essential that each pair of simple curves, forming the *compound curve* have a common tangent where they meet. For smooth running, the practice is to introduce a *transition curve* (*vide* para 1311) between the simple curves.

Reverse curves consist of two or more simple curves, the adjoining curves being of contrary flexure, namely, if one curve turns to the left the adjoining curve turns to the right and the two curves form the letter S. Transition curves are introduced between the simple curves forming the reverse curve in order to obtain smooth running.

1305. Superelevation or cant

When a body moves in a circular path, it has a tendency to move off the path in a tangential direction. This tendency is due to the body having a constant radial acceleration, when moving over a curved path, which produces a force, known as the centrifugal force. This force has to be counteracted if the body is to follow the circular path and this counteracting force is known as the centripetal force. If the two rails of the track on a curve were level, the centripetal force necessary to counteract this would be exerted by the outer rail pressing against the wheel flanges.

Not only would the rail be rapidly worn away, but the track would constantly be moved out of position. Considerable possibilities of derailment, due to flanges of wheels mounting the rails, would also exist. The force, necessary to keep a vehicle in a

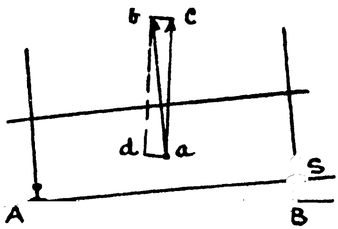


Fig. 1305

circular path, is obtained by raising or superelevating the outer rail of a curve slightly above the inner rail. In Fig. 1305, BS is the superelevation given to the outer rail, ab is the rail reaction, of which ac is the vertical component and ad the horizontal component. The result of raising the outer rail is to obtain a horizontal component of rail reaction and this horizontal component helps to keep the vehicle on the circular path. Triangles ABS and abc are similar, hence

$$\frac{BS}{AB}=\frac{bc}{ac}=\frac{ad}{ac}$$

hence the superelevation $BS=AB\,\frac{ad}{ac}$. AB may be taken as the gauge, although it is not accurately so, and the counteracting force,

$$ad=\frac{\text{weight}\times\text{velocity}^2}{\text{radius}\times\text{acceleration due to gravity}}$$

$$ad=\frac{Ws^2}{rg}$$

$$\text{Hence superelevation}=G\,\frac{Ws^2}{rg}\times\frac{1}{W}=\frac{Gs^2}{rg}$$

When G = gauge in feet
W = axle load
s = speed in feet per sec.

If we substitute s by V, the speed in miles per hour, replace g by its value 32.2, and obtain the superelevation in inches, the formula becomes :—

$$\text{Superelevation in inches}=\frac{G}{32.2r}(1.47)^2\,V^2\times 12,$$

since speed in feet per sec. $=1.47\times$ speed in miles per hour.

$$\text{Superelevation } e=\frac{GV^2}{1.25r}.$$

Substituting the values of the various gauges, the above formula becomes :

$$\text{For B.G. : } e=\frac{5.5V^2}{12.5r}\ \textit{i.e.}\ \frac{4.4\,V^2}{r}$$

$$\text{For M.G.: } e=\frac{2.62V^2}{r}$$

$$\text{For N.G. : } e=\frac{2V^2}{r}.$$

As superelevation varies with the square of the speed, the superelevation given for a speed of 60 miles per hour would not suit any other speed. As it is impossible to change the superelevation with varying speeds, a compromise has to be adopted. On some railways, the superelevation is given for the maximum speed, if the majority of trains are fast trains. The majority of railways, however, provide superelevation for average speeds. The method of determining the average speed varies; sometimes three-quarters and sometimes two-thirds the maximum speed, is taken as the average. On some railways, the product of the number of trains and the speed of each train is divided by the total number of trains and the average arrived at is known as the *weighted average*.

There are limits to the amount of superelevation which may be given with safety. If there is too much superelevation, vehicles passing over the curve at slow speed not only cause heavy wear, both on their fittings and on the track, due to too much weight being thrown on the inner rail, but the outer lightly loaded wheels have a tendency to derail. A further increase in superelevation may even affect the stability of a stationary vehicle. For these reasons, when the superelevation is given for maximum speeds, the maximum difference in speed between the fastest and the slowest train is sometimes stipulated. This difference may be about 15 to 20 miles per hour. In India, superelevation is limited to $6\frac{1}{2}''$ for broad, $4''$ for metre, and $3''$ for narrow gauges. In Britain, $7\frac{1}{2}''$, and in America, $6''$ have been specified as the maximum limits for $4\text{-}8\frac{1}{2}''$ gauge. Appendix 11 gives the superelevation at various speeds and the speed limit on curves.

It is obvious that full superelevation cannot be given suddenly at the tangent point, the reduction in superelevation being carried from zero to the maximum necessary. Formerly, it was usual to give full superelevation at the tangent point and to reduce this gradually on the straight track at the rate of $1''$ or less per $30'$. If, for instance, the full superelevation was $4''$, there would be varying superelevation on the straight track upto a point $120'$ from the tangent point. Sometimes only half the superelevation was given at the tangent point, the reduction in superelevation being carried out partly on the straight and partly on the curve. In both methods, the superelevation except at one point was either greater or less than that required at each point. This produced rough running, particularly bad lurches, and increased the wear and tear on vehicles and track at the ends of the curve. With the introduction of transition curves, explained in para 1311, the difficulty of obtaining the correct superelevation at the ends of a curve was solved. Superelevation varies from zero at the beginning

of a transition curve to the full amount at the junction of the transition and circular curves and the correct amount is obtained at every point of the transition curve.

It may be noted that a single deficiency or excess of superelevation does not produce as much rough running and wear of vehicles and track as lack of uniformity in superelevation. Hence superelevation should be maintained constant throughout the circular curve and varied at a uniform rate over the transition curves.

1306. Speed of trains on curves

The speeds at which trains may be allowed to negotiate curves safely depend on several factors such as the gauge, the distance at which the resultant of the weight of the vehicle and its centrifugal force falls outside the centre of the track, the superelevation, and the existence or absence of transition curves at the ends of the circular curve. In India, the following formulæ are used for the maximum permissible speeds, where transition curves are provided.

For broad and metre gauges $V = 1.5\sqrt{R - 220}$.

For narrow gauge $V = 1.25\sqrt{R - 20}$ limited to 30 miles per hour.

For curves without transitions, the above speeds are reduced by 20%. For narrow gauge tracks, the maximum speed limit on curves without transitions is 25 miles per hour.

1307. Extra clearances on curves

Mention has been made in para 112 of the minimum distance required between moving vehicles and any structure adjoining the track. Such distances or clearances have to be increased on curves due to the effect of curvature on long vehicles, the lean of the vehicles due to superelevation and the extra lurch or sway of vehicles when moving round a curve.

In Fig. 1301, A and B are assumed to be centres of bogies of a vehicle moving round a curve ACB. As the body of the vehicle does not bend, it will lie along the chord AB, overhanging the track by a maximum distance PC. As PC is the versine on chord AB, its value is equal to $\frac{AB^2}{8r}$ (*vide* para 1301).

The maximum distances of bogies are 48′ for broad, 45′ for metre and 33′-9″ for narrow gauges. The extra clearance required due to curvature, for instance, on a 4° curve on broad gauge is

$$\frac{(48)^2}{8} \times \frac{4}{5730} \times 12 = 2.4 \text{ inches.}$$

It should be noted that the body of the vehicle extends beyond the bogies and an extra clearance is required for this overhang also. The clearances worked out as above are sufficient for the end overhang.

If, in Fig. 1305, *ab* is the height of a vehicle, the centre of the top of the vehicle is a distance *ad* away from the centre of the track. Any structure adjoining a curved track should therefore be given an extra clearance equal to *ad*. From similar triangles

$$abd \text{ and ABS, } \frac{ad}{ab} = \frac{\text{BS}}{\text{AS}} \text{ or } ad = \frac{ab \times \text{BS}}{\text{AS}}$$

$$\text{hence } ad = \frac{\text{height of vehicle} \times \text{superelevation}}{\text{gauge of track}}$$

This extra clearance due to the lean of the vehicle is required only on the inside of a curve, as the vehicle leans only in this direction.

Allowance is made in the clearance required on the straight line on account of the swaying or lurching of vehicle from side to side, due to the effect of springs and irregularities in track. The tendency to sway is increased on curves and an additional clearance, equal to one-fourth of the clearance due to lean of vehicle, is provided. This additional clearance is again not required on the outside of the curve, as the lurch is in a direction opposite to that of the inward lean due to superelevation.

To summarise, extra clearance is to be provided (1) on the inside of a curve for the effect of curvature, lean due to superelevation and additional sway of vehicles, and (2) on the outside of a curve for the effect of curvature only. The amounts necessary are given in Appendix 12, item 23.

1308. Method of ascertaining the degree and superelevation of a curve in the field

It is often necessary to find out by measurement in the field the degree or radius of an existing curve. The amount of superelevation necessary is also required to be checked by some simple measurement, although indicators for this are usually provided along the curved track. To find the degree of curve, the versine

is measured on a 62′ chord and the versine read in inches is equal to the degree of curve. Similarly the correct superelevation may be determined by measuring the versine on an appropriate chord.

As stated in para 1301,

$$\text{versine V} = \frac{(\text{chord})^2}{8r} \text{ or } \frac{C^2}{8r}$$

where C is the chord.

$$v = \frac{C^2 D}{8 \times 5730} \text{ since radius } r = \frac{D \text{ (degree of curve)}}{5730}$$

If v in inches is to represent the degree of curvature

$$\text{then } \frac{D}{12} \text{ must equal } \frac{C^2 D}{8 \times 5730}$$

hence $C^2 = 3820$ and $C = 61.8'$ or say 62′.

Again if the versine of a chord is to represent the superelevation, the superelevation in inches must equal the versine in inches.

$$\text{namely } \frac{GC^2}{1.25r} (\textit{vide} \text{ para 1305}) = \frac{C^2}{8r} \times 12$$

$$\text{hence } C^2 = \frac{GV^2 \times 8}{1.25 \times 12} = 0.533 \text{ GV}^2$$

For broad gauge, G is 5.5 and $C = \sqrt{.533 \times 5.5}\ V = 1.713\ V$

If the average speed for superelevation is taken as 45 miles per hour, the length of chord required is $1.713 \times 45 = 77.08''$ say 77′ and the versine read with this chord gives the necessary superelevation.

For metre gauge, $C = \sqrt{.533 \times 3.281}\ V = 1.322\ V$

If the average speed is taken as 35 miles per hour, the versine on a chord 1.322×35 namely 46.27′ say 46′ gives the superelevation.

For narrow gauge, $C = \sqrt{.533 \times 2.5}\ V = 1.154\ V$

Taking the average speed for superelevation as 20 miles per hour, the chord length for finding superelevation from its versine is $1.154 \times 20 = 23.08'$, say 23′.

1309. Deficiency in superelevation and negative superelevation

When a curve has a set of points and crossings located on it and the turnout, or diverging track, curves in a direction opposite to that of the main curve, the superelevation necessary for the average speed of trains running over the main curve cannot be

given. The speed of trains over the diverging track has to be considerably reduced, and the speed over the curved main track may also have to be reduced. The reason for these reductions is that, on the diverging or branch track, the inner rail becomes higher than the outer rail (*vide* Fig. 1309). The rail AB of the main track is higher than rail CD, hence point B is higher than point D, but for the turnout track, point D should be higher than point B.

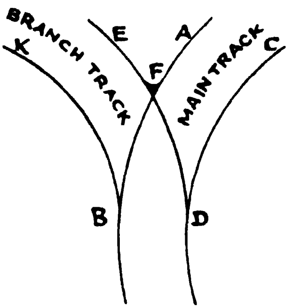


Fig. 1309

A certain amount of deficiency in superelevation is however allowed without corresponding reduction in speed to overcome such difficulties. Deficiency in superelevation is the amount by which the actual superelevation falls short of the equilibrium superelevation, namely that calculated from the formulæ given in para 1305. The deficiency in superelevation is limited to 3″ for B.G., and 2″ for M.G., without a corresponding reduction in speed. For instance, if the required superelevation is 4″ and the deficiency in superelevation permitted is 3″, the speed need not be reduced if 4″—3″ – 1″ superelevation is provided. This means that in the above case, point B will be kept 1″ higher than point D.

As a result, on the branch track, there is a negative or reverse superelevation of 1″ that is, instead of the outer rail DE being higher, it is 1″ lower than the inner rail BK. The negative superelevation on the diverging track and the reduction in speed over the main curved track are calculated as follows.

For B. G. and M. G., the equilibrium superelevation necessary over the diverging track is worked out from the formulæ in para 1305. The permissible deficiency is deducted from the equilibrium superelevation and the resultant figure is the negative superelevation to be given on the turnout track. This is also equal to the maximum superelevation permitted on the main curved track. For example, if a B.G. diverging track curve is of 6°, the equilibrium superelevation at 20 miles per hour is

$$\frac{4.4V^2}{r} = \frac{4.4 \times 20 \times 20 \times 6}{5730} = 1.84''.$$

The negative superelevation is then 1.84″—3″=1.16″. The maximum superelevation that can be given to the main curved track is also 1.16″. Speed on the main curved track has to be restricted and this

restriction is obtained by adding the permissible deficiency in superelevation to the actual superelevation and applying the formula in para 1305. In the above example, the theoretical superelevation is $1.16'' + 3'' = 4.16''$ and the maximum permissible speed is obtained from

$$4.16'' = \frac{4.4V^2}{r}.$$

If the main curved track is of 2°, then

$$4.16'' = \frac{4.4V^2 \times 2}{5730}$$

from which the maximum permissible speed works out to 54.6 miles per hour.

For N.G., the negative superelevation is limited to 1/60th of the gauge, namely, $\frac{1}{2}''$, and the maximum speed over the curved main track is restricted to $0.5r$. If, therefore, a diverging track takes off a main track on a 5° curve, the speed over the main track is restricted to

$$\frac{.5 \times 5730}{5} = 24 \text{ miles per hour.}$$

If the diverging track curves in the same direction as the main curved track, negative superelevation does not occur. The superelevation, which in this case is the same for the main and the diverging curves, is obtained by finding the equilibrium superelevation for the diverging track. The maximum permissible speed on the main curve is obtained by adding the permissible deficiency to the equilibrium superelevation and applying the formulæ as above. It is usually laid down that superelevation should be constant on a certain length of a curve from which a turnout is taken. The length concerned is a distance x beyond the crossing point F (Fig. 1309) to an equal distance x beyond the switch point. The minimum distance is fixed at 60′ for B.G., 50′ for M.G., and 40′ for N.G. The only exception made is where negative superelevation is permitted as explained above. In Fig. 1309, point D is lower than point B and also point F, by an amount equal to the superelevation. A change in superelevation is necessary between points D and F on the turnout curve DFE, as the level of the point F must be the same for both main and turnout tracks.

1310. Grade compensation for curves

In para 109 the ruling gradient was defined as the maximum gradient of a particular section. If a curve lies on a ruling gradient, the resistance due to the gradient is increased by that due to the curvature and this increases the resistance beyond the maximum

contemplated by the ruling gradient. In order to avoid resistances beyond the set limit, gradients are reduced on curves and such reduction is known as grade compensation for curves. There are many variable factors in the calculation of curve resistance, but it is taken as a percentage per degree of curve. The curve resistance is greater at lower speeds.

In India, compensation for curvature is given at .04 per cent per degree of curve for broad gauge, and .01 for metre gauge. On the 4′-8½″ gauge, the percentage compensation varies from .03% to .04% in America and is as much as .05% per degree in Britain. For example, if the ruling gradient is 1 in 200, or .5%, and if a 3 degree curve is situated on it, the gradient is to be reduced on broad gauge track by $.04 \times 3 = .12\%$. Hence the actual grade on a 3° curve, equivalent to a ruling grade of 1 in 200, is $.5 - .12 = .38$ or 1 in 264.

1311. Transition curves

When a train is travelling over a curve at a uniform speed s, it has a constant radial acceleration of s/r feet per second where s is the velocity in feet per second and r is the radius of curve in feet. This produces a certain force, namely, the centrifugal force. As long as this force remains uniform, or is increased or decreased at a uniform limited rate, no discomfort is felt by those in the train. A train travelling over a straight track with a uniform speed has no radial acceleration. It will, therefore, be seen that when a train enters a circular curve from a straight, the full radial acceleration is conveyed to the vehicle. The radial acceleration is counteracted by superelevating the outer rail on the curve. As the intensity of the radial acceleration varies as the square of the speed, the superelevation given on a curve, is only correct for one particular speed. The stability of the vehicle is however retained by the thrust of the outer rail against the outer wheel flange if the speed is below the superelevation speed. The change from a straight to a circular curve is instantaneous at the tangent point and therefore full radial acceleration exists at the tangent point. The outer rail, however, cannot be raised a few inches suddenly above the inner rail at the tangent point, and the superelevation can only be attained gradually. This results in unbalanced forces over the length required for obtaining full superelevation. Apart from the unbalanced forces being unsafe, if excessive, and also being detrimental to the vehicles and track, great discomfort is felt if the radial acceleration is attained suddenly or above a certain rate. The maximum rate of increase or decrease in radial acceleration, producing

a force which does not cause discomfort, has been found from practice to be a little over 1 foot per second in one second. If speeds are low, great discomfort is not felt, as part of the force is taken up by the springs of the vehicles and by the play in the axle boxes. Discomfort is also reduced due to only one out of two or more axles, and not the whole vehicle, passing the tangent point instantaneously. With high speeds and sharp curves, it is necessary, not only in order to reduce discomfort, but also from the point of safety, to introduce a transition curve between the straight and the circular curve. The radius of curvature of a transition curve diminishes from infinity, at the junction with the straight, to that of the circular curve and the radial acceleration therefore changes uniformly; in other words, the rate of change of radial acceleration is constant.

The radius or degree of curve at any point on the transition curve varies as its distance from the tangent point. A curve fulfilling this condition is a spiral radioide, but the formula for this curve is very complicated. A cubic parabola, in which the ordinate at any point is proportional to the cube of the distance from the starting point, fulfils the condition for all practical purposes and is commonly used. The superelevation is zero at the tangent point and reaches the full amount at the junction with the circular curve. This superelevation equals the exact amount required at all points on the curve, instead of being more or less than that required at each point, as is the case where a transition curve is not interposed between the straight and the circular curve.

The following procedure is adopted in setting out a transition curve for new tracks. If transition curves are to be introduced into existing tracks the method given in para 1313 should be adopted. In Fig. 1311, K_1 K_2 is a circular curve with A_1 K_1 and A_2 K_2 as tangents and I, the intersection point. The tangent point K_1 is obtained by measuring back the tangent distance IK_1. In order that a transition curve may be introduced so that one end of it is tangential to the straight and the other end tangential to the circular curve, the latter has to be set back from the position which it would occupy if there was no transition curve. Point A_1, the beginning of the transition curve, is obtained by measuring back a distance equal to half the length of the transition curve plus the shift multiplied by the contangent of O, where O is the angle shown in Fig. 1311. The shift is the distance by which the tangents are moved sideways to accommodate the transition curves. The values of the lengths of transition curves and the shift are given later. At point S, half transition curve length from A_1, a perpendicular S P_1 and equal to the shift is obtained with a theodolite.

M_1 is the middle point of S P_1. Another perpendicular A_1 F_1 is similarly obtained at point A_1. Then F_1 P_1 Z and similarly

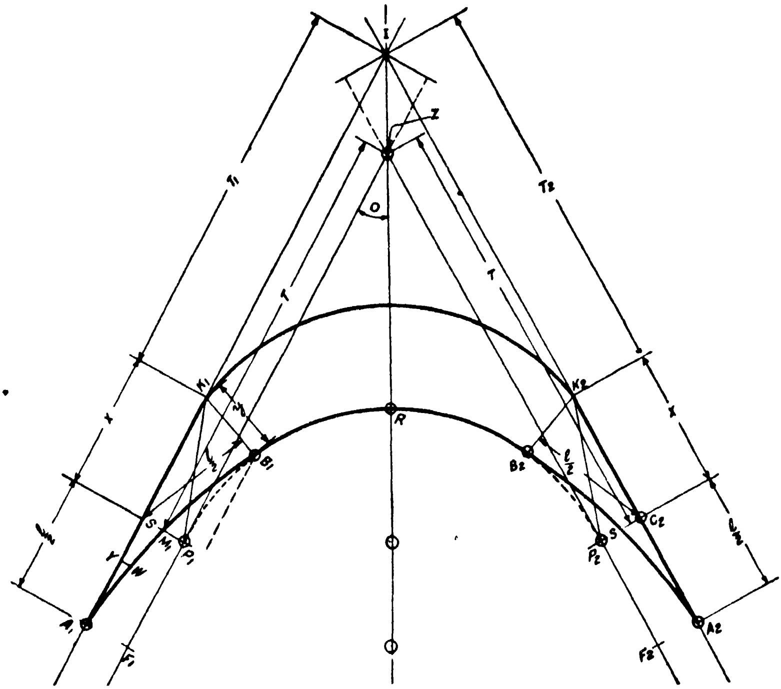


Fig 1311

F_2 P_2 Z are the tangents for the shifted circular curve, Z being the new intersection point. From P_1 a chord P_1 B_1 of length equal to half the transition curve length, is measured to the shifted circular curve and point B_1 is obtained. The transition circular curve is located from tangent points P_1 and P_2 as explained in para 1302. Additional points on the transition curve are obtained as follows. For any point W,

$$\frac{\text{Offset YW}}{(\text{distance } A_1 \text{ Y})^3} = \frac{M_1 \text{ S}}{(A_1 \text{ S})^3}$$

since the offset varies as the cube of the distance in a cubic parabola.

$$\text{Offset Y W} = \frac{M_1 \text{ S} \times (A_1 \text{ Y})^3}{(A_1 \text{ S})^3} = \frac{\text{half the shift}}{(\text{half the transition length})^3} (A_1 \text{ Y})^3$$

The shift $= \dfrac{l^2}{24r}$ where l is the length of the transition curve and r is the radius of the circular curve.

The length of the transition curve may be determined by the maximum permissible rate of change of radial acceleration, namely 1 foot per sec.^{2} in one second as mentioned above. If s is the velocity in feet/sec. the change of acceleration in a distance of s feet, which is covered in one second, is not to exceed 1 ft./sec.^{2}. Therefore the change of acceleration in a distance of 1 foot is not to exceed l/s ft./sec.^{2}. Hence the change of acceleration in a distance l, which may be the length of the transition curve, is not to exceed l/s ft./sec.^{2}. In other words, the radial acceleration at the end of a transition curve of length $l = l/s$ ft./sec.^{2}. But the radial acceleration at the end of a transition curve must be the same as the radial acceleration of the circular curve. The value of the radial acceleration of a circular curve is s^2/r

$$\text{Hence } l/s = s^2/r$$

and l, the length of the transition curve, $= s^3/r$ where s is the velocity in ft./sec.

The length of a transition curve may also be fixed according to the rate of change of superelevation. This is specified as a maximum of 1 in 360 i.e. 1″ per 30′ length for broad gauge. If the superelevation, worked out for a particular curve, is 5″, the length of transition curve would be $5 \times 30' = 150'$. Another method, suggested for obtaining the length of transition curves, is that it should be based on the rate of change of shortage in superelevation. As already explained, superelevation is based on average speeds. If the superelevation is worked out for the maximum speed as well, the difference between these two superelevations is the shortage in superelevation. This shortage is multiplied by the maximum speed in feet per second and the figure obtained is taken as the length of the transition curve. The assumption is that, for comfort, the rate of change in the shortage should not be greater than 1″ per second.

1312. Vertical curves

When a change occurs in the gradient of the track, namely when a rising gradient changes to a falling gradient or *vice versa*, or a rising or falling gradient is increased or decreased, an angle is formed at the junction of the gradients. This obviously cannot be allowed to remain in a track as it would form a vertical kink. The two gradients are therefore connected by a curve in a vertical plane. A vertical curve is in the shape of a parabola and its length depends on the difference in the gradients. The length of a vertical curve, where say a falling grade changes to a rising grade, is

greater than the length of the curve where a falling grade becomes steeper. Such curves have to be considered when building the formation of the track. When a rising gradient is followed by a falling gradient, or *vice versa*, it is good practice to have a level stretch of track between the rising and the falling gradients.

1313. Realigning curves and introducing transition curves

(1) *Necessity:* A railway curve, however well it may have been set out and however carefully it may have been maintained, does not retain its correct alignment due to the large horizontal force exerted on the rails by passing trains. The curve gradually develops horizontal waves, certain portions having smaller radii than the neighbouring lengths. Since acceleration varies inversely as r, if the radius of a curve varies from point to point, rough running is felt on the curve. Moreover, at the ends of the curve, if the radius does not change uniformly from infinity to the radius of the circular curve, namely, if the alignment of the transition curve is not correct, the rate of change of central acceleration is not uniform and is likely to exceed the limits prescribed in para 1311, resulting in discomfort. For high speeds and greater comfort, improvements of such curves is not only desirable but also necessary. As the centrifugal force varies as the square of the velocity, the centrifugal force exerted at a speed of 60 miles per hour is $2\frac{1}{4}$ times as great as that at 40 miles per hour, since $60^2/40^2 = 2\frac{1}{4}$. Any increase in speed, on account of the very great increase in the centrifugal force, has a tendency to throw out the alignment on curves, particularly if the superelevation is not correct or if the ballast support is weak. The maximum speed of passenger trains in India is 60 to 65 miles per hour; in some countries speeds of over 100 miles per hour are not uncommon. The importance of reconditioning of curves with such speeds can be easily realised.

(2) *String lining:* The alignment of railway curves may be corrected with the help of a theodolite. The procedure would be to survey the existing curve, plot the results, work out the proposed alterations and set out the revised alignment. This method is, however, lengthy and expensive and many difficulties have to be solved in setting out, as the instrument has to be fixed often off the embankment or cutting, and when fixed on the track, it has to be removed often to let trains pass. A method, known as *string lining*, has been developed in which defective curves can be realigned by correcting the versines on a series of chords. In order to avoid much shifting of the track, the new alignment in string lining methods is sometimes worked out so that the

realigned curve consists of a compound curve, made up of two or more curves, with very slight variation in the degree of curvature.

Several methods of string lining have been developed within recent years, both in India and abroad, and excellent results have been obtained. String lining depends fundamentally on the relation between the radius of a curve and its versines.

(3) *Method:* As long as the radial acceleration, mentioned in para 1311 remains constant, or is increased or decreased at a uniform limited rate normally not exceeding one foot per second per second in one second, no discomfort is felt by those in the train. The value of the radial acceleration is s^2/r feet per second per second where s is the speed in feet per second and r is the radius of curve in feet. In order to make the radial acceleration constant, the radius r must be kept constant.

But as stated in para (1), the radius of an existing curve is found to vary considerably, hence its versines must also vary. If some method is adopted, by which versines are made uniform over the circular curve and are made to change at a uniform and limited rate (limited so as to cause an acceleration normally not exceeding 1 foot per second per second in one second) over the transition portions of the curve, the running over the curve is improved. The chord normally chosen, on which the versines are read, is of 62′ length.

Realigning consists of adjusting the alignment of an existing curve, either (1) to obtain a uniform circular curve with transition curves at either tangent or (2) to form a compound curve, with transitions at either tangent as well as between the circular curves of different degrees forming the compound curve.

In all string lining methods, existing versines are measured at half chord lengths. Versines, fulfilling conditions (1) and (2) given above, are then calculated or plotted. The amount by which each existing versine is to be altered is marked on the track and the curve is slewed at each half chord length by this amount. The superelevation is also corrected to conform with the radii of the new curves.

(4) *Fundamental principles:* Two fundamental principles, on which all string lining methods are based, are given below :

(i) The difference between the sum of the versines of any two curves, having common tangents and a common intersection angle is zero.

(ii) The difference between the sum of the *throws* of any two curves, having common tangents and common intersection angle, is zero

Note —The throw of a point on any curve is the distance of that point with respect to any particular chord, measured along the arc of a radius, equal to the distance of the point from the intersection of the chord concerned with the curve. In a curve ABCD (Fig 1313*a*) the throw of point C with respect to semi-chord AB is CH Similarly the throw of point D with respect to semi-chord AB is DF.

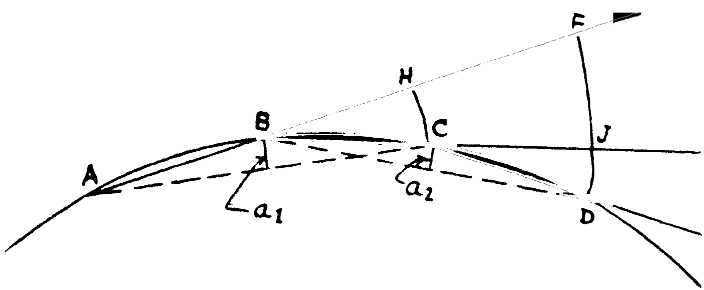


Fig 1313*a*

In Fig. 1313*a*, ABCD represents a railway curve, AB, BC, CD, being half chord lengths *c* and AC, BD, being full chords, a_1, a_2 are versines on chords AC and BD

$$\text{Sin BAC} = \frac{a_1}{c} \text{ and since } \angle \text{BAC is very small}$$

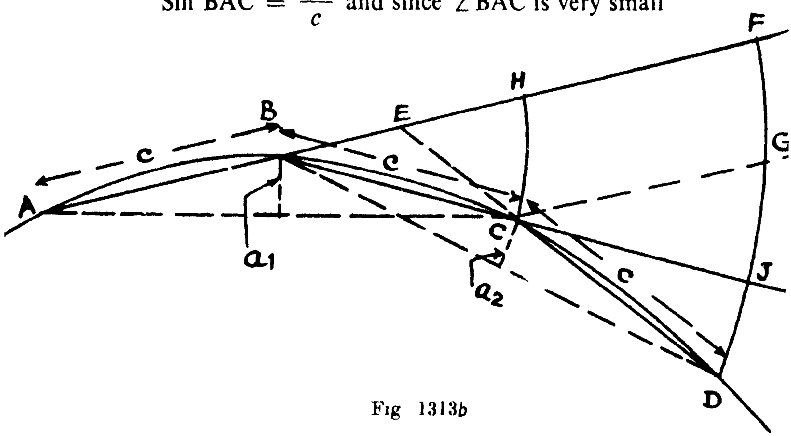


Fig 1313*b*

$$\angle BAC = \frac{a_1}{c} \text{ also } \angle CBD = \frac{a_2}{c} \text{ and so on}$$

$$\angle FBC = 2 \angle BAC = \frac{2a_1}{c}$$

$$\angle JCD = 2 \angle CBD = \frac{2a_2}{c} \text{ etc.}$$

The intersection angle between Chords AB and CD two stations apart (Fig. 1313*b*) is $\angle FED$.

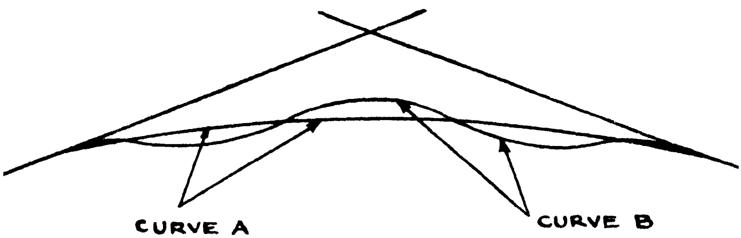


Fig. 1313*c*

$$\begin{aligned}\angle FED &= \angle GCD \\ &= \angle GCJ + \angle JCD \\ &= \angle FBC + \angle JCD \\ &= \frac{2a_1}{c} + \frac{2a_2}{c} \\ &= \frac{2}{c}(a_1 + a_2)\end{aligned}$$

Similarly, the intersection angle between two chords three stations apart $= \frac{2}{c}(a_1 + a_2 + a_3)$.

If two curves start and finish at the same point, and have common tangents, they must also have a common intersection angle. If they vary slightly for parts of their length (*vide* Fig. 1313*c*) the versines, measured on a standard chord, will vary, but the sum of the versines of the two curves must be the same, as the

intersection angle is common and is made up of the sum of the versines as shown above. It follows therefore that the difference between the sum of the versines of these two curves is zero.

The throw of point D (Fig. 1313*b*) with respect to Chord AB is the arc DF. Since the arc DF is very small compared to its radius, it may be considered to be made up of (i) arc DJ with radius CD (i.e. c) and $\angle$JCD and (ii) arc JF with radius BF (i.e. $2c$) and $\angle$FBJ.

Fig. 1313*b* is exaggerated for clearness, the curve in practice being very much flatter than that shown in the figure and the arcs correspondingly smaller.

$$\text{Arc DJ} = c \times \angle \text{JCD}$$

$$= c\,\frac{2a_2}{c} = 2a_2$$

$$\text{Arc JF} = 2c\ \angle \text{FBC}$$

$$= 2c\,\frac{2a_1}{c} = 4\,a_1$$

$$\text{Hence Arc DF} = 2a_2 + 4a_1$$

$$= 2\,(a_2 + 2a_1)$$

The throw FD, in Fig. 1313*b*, is therefore equal to $2\,(a_2 + 2a_1)$ where a_1 and a_2 are versines on chords AC and BD. Similarly for any point D on the curve, any number of half chord lengths away from AB, the throw is equal to twice the sum of each versine multiplied by the distance (in half chord lengths) of the versine from the point considered.

The versine multiplied by the distance, in number of half chord lengths, from the point is termed the *Moment of versines*. Hence throw is equal to twice the sum of the Moments of versines.

In two curves varying slightly for part of their lengths, the distance between them at any point is equal to the difference between the throws at that point on each curve with respect to a common chord. Hence, if the difference between the throws are obtained between an existing curve and an *Ideal* curve, the amounts by which an existing curve is to be slewed, i.e. the *shifts* at each half chord point, are known.

The sum of the moments of versines of curve A (Fig. 1313*c*) must be equal to the sum of the moments of versines of curve B, or, in other words the difference between the moments of the versines of curve A and curve B is zero. If the difference is not zero, the end of the curve would have to be slewed by an amoun

equal to the shift, but this is not permissible as there must be no slew at the end of the curve, otherwise the new curve will not be tangential to the existing straights.

(5) *Method of calculations:* Of the several string lining methods,* the one in which calculations only are used, is the simplest. For this method, tabulation sheets similar to the example in Appendix 18 are used.

The *versines* of the existing curve as measured are recorded in column 2 (Appendix 18), with the *station numbers* in column 1, each station being a semi-chord length away from the adjoining station. *Ideal* or *revised* versines are selected and entered in column 3. *Differences* between the ideal and the existing versines are recorded in column 4. The *sum of the differences* between the ideal and the existing versines, must be zero, if condition (i) in para 1313(4) is to be fulfilled. The figures in column 4, i.e. the differences of the existing and ideal versines, are added together in column 5 and the total of this column must be zero.

The sum of the differences are once again added together and entered in column 6. The result gives the *moments of the differences* of versines. The total of column 6 must again be zero, if condition (ii) in para 1313(4) is to be fulfilled. Twice the values in column 6 give the *shift* at each station. The proof of this statement is given in Appendix 15(1).

In order to fulfil the first condition, the sum of the differences of ideal and existing versine must be zero, hence when the *Sum* column is totalled, the result must be zero. Again, in order to fulfil the second condition, the sum of the moments of the difference of versine must be zero. In other words, when the *Moments* column is totalled, the result must again be zero. A large number of trials are necessary before the ideal versines are so selected as to make the total of the sum and of the moment column zero. Considerable time would be wasted by this trial and error method and the results would not be satisfactory. A more satisfactory method is to carry out *adjustments* to obtain the required results and these adjustments can be effected by making slight alterations in the ideal versines. The effect of alterations in the ideal versines on the sum of differences and on the moments of differences, is illustrated by Tables I and II of Appendix 15(2).

In Table I, the increase by a unit in ideal versines, and therefore the difference between the ideal and existing versines of one unit

*For a study of the various string lining methods the reader is referred to the author's paper on "Reconditioning of Railway Track on Curves," in the *Journal of the Institution of Engineers (India).*

at stations 1; 1 and 2; 1, 2 and 3, and so on, are shown in sub-columns *a* to *j* of column 2. The effect of such alterations on the sum of the differences of versines and on the moments of the differences of versines, are shown in corresponding sub-columns under these heads. If the ideal versine is increased by 1 at station 1, the sum of the differences is increased by 1, and the moment of differences by 9 at station 10. An increase in ideal versine at stations 1 to 10, results in an increase in the sum of the differences by 10 and in the moment of differences by 45 at station 10.

When reconditioning a curve by this method, if the sum of differences at the end of the curves comes to say —3, all that is necessary to be done, is to add +1 to the versines at any three stations, to bring the total of this column to zero. The increase in versine at a few stations by a unit, i.e. 1/100th inch (as all versine units used are in hundredths of an inch) will affect the degree or radius of the curve very slightly and will be immaterial so far as running over the curve and appearance are concerned. With 62′ chords, alterations of 1/100 in versine, results in an alteration of 0.01 degree in the degree of curve and this is negligible.

The moments of differences in the versine column of Table 1 are particularly useful when working out the revised curve, as it is easy to see at which station a slight change in versine is to be carried out, in order to increase or reduce the *Moment* alterations in versine at any other station by any particular amount. For instance, if the moment of difference of versines is to be reduced by 39 at station 10, all that is required is to decrease by 1 the versines at six consecutive stations, e.g. 1, 2, 3, 4, 5 and 6 (*vide* sub-column *f*).

If the above alterations in the moments are required for bringing the total of this column to zero, to fulfil the second condition, the above solution is not possible, as the reduction in versines at six consecutive stations also reduces the sum by 6, and this affects the total of the sum column, which has already been brought to zero. The difficulty is overcome as shown in Table II. In this table, the results of increasing a versine at one station and decreasing at any other station, are illustrated. For instance, if the versine at any station 1 is increased by 1, and decreased at a place 8 stations away, i.e. at station 9, the total of the sum will not be affected as a result, but the total of the moments will be increased by 8 (*vide* sub-column *l*). In order that the total of the sum may not be affected, the versines are altered in couples and such adjustments are known as *correcting couples*. The value of the correcting couples need not necessarily be 1, but may be any small figure, provided this does not result

in too abrupt a change in the revised versine. It will also be seen that the amount by which the moment is altered is equal to the product of the alteration in versine (in the table this is given as 1), and the difference between the station numbers of the plus and minus versines, e.g. station 9 minus station 1 equals 8, and this is the value of the moment. More than 1 pair of versines may be altered. The results on the moments are accumulative, as is evident from the sub-column *n*.

(6) *Sequence of steps:* The sequence of steps, for reconditioning a curve by this method, is as follows. A simple example is given in Appendix 15(3).

(i) The existing versines are recorded in column 2.

(ii) These versines are totalled up for the portion which appears to be a circular curve, i.e. where the versines are more or less constant; the end transition portions are ignored. The total of these versines is divided by the number of stations covered by these versines, and an average versine for the ideal circular curve is obtained and entered in column 3 against the same stations.

(iii) The limiting value of the change in versine of the transition curve is worked out from the formula $6c^3/s^3$.

The proof is as follows :—

As explained in para 1301, the versine is equal to $C^2/8r$ where C is the length of the chord. If semi-chord length c is used, since $C=2c$, versine $v=c^2/2r$. As acceleration in one second is normally not to exceed 1 foot per second, if s is the speed in feet per second, the change of acceleration in a distance of 1 foot is not to exceed $1/s$ foot per second per second. Hence the change of acceleration in a distance equal to the semi-chord length c is not to exceed c/s foot per second per second. But acceleration is equal to s^2/r. This may be written as $\frac{s^2 \times 2v}{c^2}$, since $v = \frac{c^2}{2r}$. If a is the change in versine in a semi-chord length c, change in acceleration in the semi-chord length $= \frac{s^2 \times 2a}{c^2}$.

$$\text{Hence } \frac{c}{s} = \frac{s^2 \times 2a}{c^2} \text{ or } a = \frac{c^3}{2s^3}$$

If the change in versine a is given in inches, the value becomes $6c^3/s^3$.

The versines of the transition curves are selected, so that the difference between adjacent versines does not exceed this value.

With the above process, any set of versines, which correspond as close as possible to the existing versines, may be used, provided the limiting value of $6c^3/s^3$ is not exceeded between each pair of stations. These versines are entered in column 3 against the stations not covered by item (ii) above.

(iv) The difference between the ideal and existing versines are worked out in column 4. Figures in column 4 are added to give those in column 5 and similarly figures of column 5, when added, give figures of column 6, care being taken to enter the results against the correct stations.

(v) If the total of column 5 does not give zero, adjustments are carried out as per para 1313(5) before working out column 6.

(vi) If the total of column 6 does not come to zero, further adjustments as per para 1313(5) are made.

(vii) The figures in column 6 are multiplied by two and divided by 100, to obtain the shift in inches by which each station on the curve is to be moved.

(viii) Calculations and adjustments are shown in Appendix 15(3). Occasions arise when it is expedient not to shift the existing alignment at any particular point, or to shift it within certain limits. All that is required is to see that the value of the moments at that particular station does not exceed half the value of permissible shift. Table I is very handy in solving such problems.

It should be noted that the procedure given above prescribes no limit to the amount of shift. The shift has however to be kept within predetermined limits, to avoid heavy earthwork. The cost of reconditioning a curve is usually proportional to the amount of shift. Limits of shift may be prescribed; when this is done, it is advisable to work out columns 4, 5 and 6, station by station, and to make full use of Table I for keeping the figures in column 6 within prescribed limits.

(7) *Compound and reverse curves:* The method adopted for a *compound curve* is simply an extension of the method described in para 1313(6). A transition, between the two circular curves of different radii forming the compound curve, should not be overlooked and the rate of change of versine over this intermediate transition should not exceed the limit given in para 1313(6) (iii).

A *reverse curve* is worked out as two separate simple curves, but with provisos that, at the junction between the two curves of opposite flexure:

(i) The versine difference is kept zero.

(ii) The total of the sum of the differences of versines is made zero.

(iii) The total of the moments of the differences of versines is also made zero.

The best procedure, in case of reverse curves, is to first determine the junction of the two curves of opposite flexure [*vide* para 1313(8) (xix)]. If a straight portion intervenes between the two curves, the tangent points of this straight should be determined [*vide* para 1313(8) (xviii)]. Taking the junction point, or each of the tangent points as station *o*, the semi-chord stations should be marked out in opposite directions, and each curve treated as a simple curve. It is obvious that, with this procedure, there will be no shift at the junction point or on the intermediate straight.

Apart from reconditioning simple or compound curves, complicated layouts in yards can also be corrected by the string lining method.

The work of realigning covers two distinct operations, namely (1) field work, including measurement of versines, fixing of pegs and slewing of the curve, and (2) calculations, as explained above and illustrated in Appendix 15(3).

(8) *Practical hints* for field work are given below:

(i) All measurements of versines should be taken with a fishing chord or piano wire, the chord being stretched between alternate stations and the versines being read at the intermediate stations. The chord should be taut. Cross sticks attached at the ends help to produce the necessary tension, the cross stick being held in one hand and the chord pressed to the running edge of the rail at the exact point by the other hand. A 100 scale should preferably be used for reading versines and the scale should be held at right angles to the chord.

(ii) Paint marks should be made on the rail at half chord length and the marks should be serially numbered.

(iii) Readings should not be taken in windy weather, as the chord will not remain steady and the readings will not be accurate.

(iv) Readings should be taken on the running edge of the outer rail. In case of double tracks, if the two tracks are exactly equidistant throughout their length and the outer track is to be realigned, by measuring off the corrected inner track, readings should be taken on the running edge of the outer rail of the inner track. This method however is not recommended for reasons given in item (ix) below.

(v) The shortest time possible should be allowed between reading of versine and fixing of revised versine stakes. To save time, the engineer or inspector who surveys the curve should also work out *slews*. If approval of higher authorities is necessary, this should be obtained promptly. Disturbance of the track in the interval due to packing, slewing, etc. should be prohibited.

(vi) Versine readings must be continued for a good distance along the tangents, to get rid of any irregularities in alignment of the tangents. It is good practice to take at least four versine readings beyond what appears to be the tangent point of the curve.

(vii) Readings must be carefully recorded on a tabulation form. It is advisable for two men to work together and to take versine readings twice, starting in the second case from the opposite end of the curve.

(viii) After the versines have been read, all limitations to slew, either away from or towards the centre of the curve, should be carefully recorded. For instance, there may be a girder bridge on the curve and the slew in either direction may be limited to, say, 3″ only. This will affect the calculations considerably.

(ix) Pegs for revised versines should be fixed in the centre of single lines and between the two tracks on double lines, if both tracks are aligned simultaneously. The minimum distance between two adjacent tracks is a fixed value and extra clearances have to be given on curves. Care is therefore necessary, in deciding on the distance between the parallel curves of a double line to ensure minimum clearances, particularly when the realigned curve is a compound curve. It must also be remembered that the radii of two parallel curves are not equal. For these reasons, it is preferable to treat each curve of a double or a quadruple track separately.

(x) After the pegs, which should not be less than 2 feet in length, are fixed as near as possible at the correct distance from the running edge of the rail, the exact distance should be marked with a brad. In fixing the brads, the measurements should be absolutely horizontal with the running edge of the rail, as any inclination will affect the distance. The most convenient and accurate method is to attach to the centre of a track gauge, an accurate scale, with the centre of the scale coinciding with the centre of the gauge.

(xi) After fixing the pegs the revised versines should be recorded as if fresh versines on the pegs were being read. These readings should be checked with those worked out theoretically and any errors corrected by local adjustments.

(xii) It is necessary, at times, to move a few sleepers slightly in order to fix pegs. This should be done as soon as station numbers are marked on the rail, so that disturbance of the track is avoided after the versines have been read on the running edge. On the other hand, the pegs may be fixed clear of the sleeper and the versine corresponding to this shorter or longer chord worked out. This method is likely to cause unnecessary complications and is not recommended.

(xiii) Whilst slewing the curve, care should be taken not to disturb the pegs.

(xiv) Speed of trains need not be restricted for any length of time after the curve has been slewed, but this is left to the discretion of the engineer or inspector.

(xv) Semi-permanent references should be fixed, preferably at each station. These may consist of lengths of flat iron, fixed at a prescribed distance from the centre line and encased in concrete. These pegs can be conveniently fixed on the concave side of curved tracks in case of both single and multiple tracks. It is not good practice to have reference pegs inside the track, as they are likely to be disturbed considerably. Superelevation references consisting of old rails with notches equal to the superelevation cut on them should be fixed at junctions of circular and transition curves. Since the superelevation is constant over the circular curve, further reference pillars are not required along the circular curve. As the superelevation varies along the transition curves, it is desirable to fix distance pegs opposite each transition with notches, equivalent to the superelevation, cut on each peg.

(xvi) A distance gauge should be given to the local gang mates for periodically checking the alignment of the curve from the reference pegs. Constant checking is necessary for some period after realignment, as the rails tend to spring back to their original position. Ballast should also be adequate to prevent this springing back.

(xvii) The reference pegs should not be taken as permanent and infallible. The author has seen reference pegs pushed completely out of position within a year, in banks formed of black cotton soil and in cuttings of indurated clay. Checking or refixing of pegs at regular intervals, say about every five years, is desirable.

(xviii) The tangent point of a short length of straight track, intervening between the two curves of opposite flexure of a reverse curve can be easily determined by stretching a chord along the running edge of a rail. The ends of the longest distance to which

the chord can be stretched without any portion of the chord losing contact with the running edge are the tangent points.

(xix) If a straight portion does not exist between two curves of opposite flexure of a reverse curve, the position of the junction point can be determined as follows:

The approximate degrees, a and b, of curvature of each of the two curves is obtained by reading the versines on 62′ chords. A length, say 100′ of string, is divided by a knot so that the knot is at a distance

$$\frac{a}{b} \times 100$$

from one end. The 100′ chord (the length is immaterial, but the longer the better) is stretched and moved longitudinally along the running edge of a rail till the knot cuts the table of the rail in the centre. The junction of the two curves is at the knot. The reasoning is simple. The relation between a semi-chord and its versine is $c^2 = 2ar$, i.e., a semi-chord varies as the square root of its versine provided the radius is constant. By dividing the string in the ratio of a/b all that is done is to obtain chords which will give the same versine on two curves with different degrees of curvature. There is only one position in which the knot will be at the centre of the rail table when the ends are held against the running edge.

1314. Mechanical calculator for realigning curves

A device known by various names such as *curve liner or curve calculator* (Fig. 1314) is available which obviates the lengthy calculations explained in para 1313. The device consists of a set of movable pointers which move along parallel graduated scales. On one side of the machine are *throw indicators* which indicate numerically the magnitude and direction of the resultant throws.

The pointers are set by means of a small crank to read the ordinates measured in the field. For adjustment of the curve, certain pointers have to be moved. This is done by means of the same crank, with certain adjustments, being engaged with the pointer concerned. Movement of the pointer now has the effect of moving the two adjacent pointers through half the movement in the opposite direction. This composite movement gives effect to the rule that a throw at any station produces a throw of half the magnitude in the opposite direction at the two adjacent stations.

The throw indicators are agreed and brought into operation when adjustments of pointers is being carried out. Adjustment of various pointers is carried out until the pointers form a smooth curve. Throws at each station are then read off directly from the throw indicators at each pointer.

Keys are available by means of which any pointer may be locked. This is done if no throw is possible at a station due to it being located on a bridge, etc.

The device is extremely simple to operate and may be easily taken into the field. The curve calculator (Matisa) in Fig. 1314 enables curves with 32 versines to be dealt with. Metal bands on the sides enable the markers to be given the field station number of the versine.

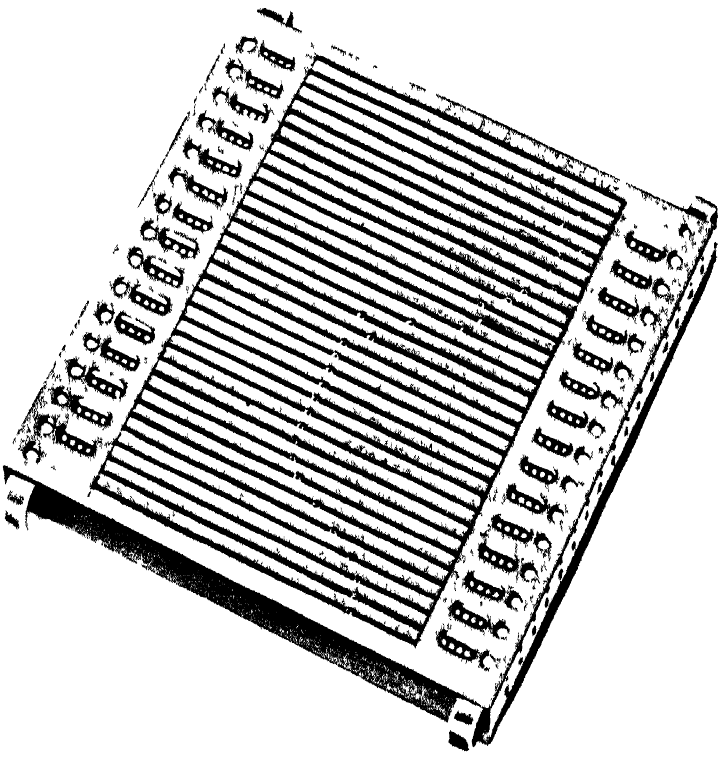


Fig. 1314

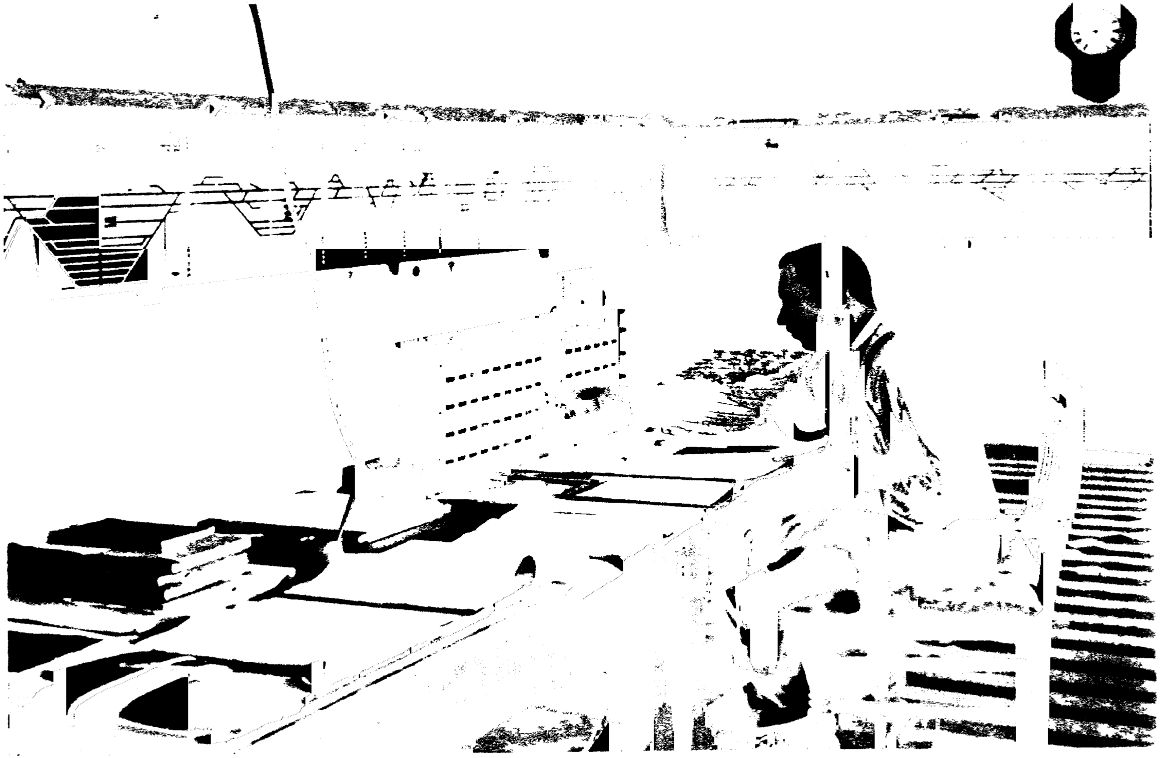
Maintenance Organisation and Inspection

1401. Track maintenance organisation

IT is not the intention here to describe in detail the organisation of the department of a railway held responsible for the maintenance of the track, but to indicate briefly the responsibility of those directly connected with track maintenance. The head of the Engineering Department responsible for the construction and maintenance of the railway track and all civil and structural engineering works is the *Chief Engineer.* He has under him one or more deputies.

A railway is divided into a number of Divisions or Districts, each under an *Executive, District or Divisional Engineer.* A Division may vary considerably in length depending on the nature and size of large yards, etc.; about 350 miles may be considered an average length.

The Division or District is divided into sub-divisions in charge of *Resident* or *Assistant Engineers. Permanent way Inspectors*



Corner of a fully equipped control room

are given charge of sections, the length of a section again depending on the extent of work, an average of 50 miles with single track being considered reasonable. Inspectors may or may not have assistants under them. Assistants are either in charge of part of the Inspector's section or for generally helping the Inspector.

1402. Section gangs

The basic unit of organisation for track maintenance is the gang length, in charge of a *gang mate*. An average gang length on a single track is three miles. In America, a foreman's length varies from 4 to 10 miles, on single track, and may be as much as 14 miles on a branch line. Consideration has to be given to the following points in deciding on the number of men required.

(1) Type of soil in formation.

(2) Age and condition of permanent way.

(3) Type of traffic, whether heavy or light.

(4) Speeds, curves, grades.

Normally on B.G. main tracks with light traffic, namely with less than 10 trains per day, two gangmen per mile are considered adequate. With heavier traffic, the number of men per mile is increased, three men per mile being necessary, if there are over 30 trains per day using the track. A slight reduction is possible on branch lines. The corresponding figures for the metre and narrow gauges may be taken as three-fourths and half of the broad gauge requirements. In order to arrive at the number of men necessary for sidings, turnouts, crossings, etc., all these items are equated to *track mile*, the track mile in such cases being considered as requiring two men. Each of the following items is considered as equal to a mile of main track.

1⅓ mile of important tracks in yards.

2 miles of other sidings in yards.

16 Turnouts.

8 Crossovers.

8 Diamond crossings.

4 Diamond crossings with double slips.

2½ Scissors crossings.

64 Single trap points.

In America, on heavy traffic lines, 2½ men per mile are considered necessary. If there are double lines, 1⅛ miles of the second

track is taken as equivalent to 1 mile. In case of multiple tracks, $1\frac{1}{3}$ miles are considered as equal to 1 mile. On branch lines, $1\frac{1}{4}$ men are allowed per mile. $3\frac{1}{3}$ miles of tracks in yards are reckoned as 1 mile of main track. Where only inspection and minor repairs are to be carried out by the section gang and all other work including adjustment of line or level, except over very short lengths, is done by special gangs, one "ganger" and two men with a trolly are in charge of 10 miles on moderate traffic lengths.

As already stated, consideration has to be given to various factors and the above figures should be taken only as a guide. With these figures it is easy to work out the number of men required in a gang in any section. For example, if in a 3 mile gang length there is a single line track with a small station containing $\frac{1}{2}$ mile of important sidings and $\frac{1}{2}$ mile of other sidings, 4 turnouts and 2 crossovers, the number of equivalent track miles is obtained as follows: $\frac{3}{4}$ of $\frac{1}{2}=\frac{3}{8}$ mile for important sidings; $\frac{1}{2}$ of $\frac{1}{2}=\frac{1}{4}$ mile for other sidings, $^4/_{16}=\frac{1}{4}$ mile for turnouts; and $\frac{2}{8}=\frac{1}{4}$ mile for crossovers. This makes a total of $4\frac{1}{8}$ miles. The gang for this section should therefore contain $4\frac{1}{8}\times2=8\frac{1}{4}$, say 8 men, in charge of a gang mate.

The work done by track gangs may be divided into *track maintenance* and *other work*. Track maintenance may be sub-divided into *routine work* and *special work*. Clearing weeds from yards, loading and unloading wagons, etc. would be classified as *other work*, whilst heavy lifting of track, say, by 2″ or more would be considered as *special work*. The figures given above are for normal routine work as indicated in para 1207. Occasional other work may also be done, but in such cases it is advisable to replace the men-days thus used up (namely, the number of men working for the number of days on that particular work) by appointing temporary men for short periods. Discretion has to be used in all such cases in deciding whether replacement is necessary and the decision is largely governed by the extent of the *other work* done. For special works, additional men in separate gangs have to be used.

1403. Massed or mobile gangs

Attempts have been made to increase the length of a section as well as the number of men in such a length and place them under the direct charge of a *Sub-Inspector* or a *Permanent way Mistry*. A trolly is provided to enable a *massed gang* to move about in its section, and due to its greater mobility such a gang is also called a *Mobile gang*. The advantages claimed for massed

gangs are that (1) the quantity of work done, by concentrating a large number of men on a particular work, is greater than with section gangs, (2) closer supervision is exercised by a more responsible person, (3) maintenance with massed gangs is more economical than with section gangs. On the other hand, (1) spot packing with massed gang suffers, as the work cannot go on simultaneously in several distant places. Postponement of spot packing leads to further deterioration of track and more work. (2) Considerable time is taken up by massed gangs proceeding to and returning from their work on a trolly as the massed gang section may be 15 miles in length. Motor trollies or rail buses may overcome this difficulty. (3) Inspection of the track by the Sub-Inspector is not possible, as he has to supervise the work of the massed gang, and if he goes on inspection frequently, the gang does not get the continuous supervision which is one of the main reasons for its existence.

In large yards, massed gangs are a distinct advantage as the work is concentrated in a limited area.

1404. Mechanisation and special gangs

In some countries the tendency is to increase the length of section gangs and to introduce large mechanised gangs.

In America, the tendency is to divide the maintenance work between section gangs and special gangs. The section gangs do spot packing, aligning, and other odd jobs essential for the proper maintenance of a track. These gangs contain very few men, an average number being three men per gang with a foreman in charge. The length of the section is about 12 miles and the gang is provided with a light motor trolly. Special gangs consist of a large number of men detailed to carry out one particular type of work only. For instance, there are special gangs for sleeper renewals only or for surfacing the track, or for ballasting only. They are sent from section to section throughout the working season and are equipped with power tools. These gangs are specialised in the work allotted to them and their output is greater than that of an equal number of section gangmen.

The advantages of this system are that

(1) Spot packing does not suffer.

(2) The output of work is greater with specialised gangs equipped with power tools.

(3) Special gangs do not have to spend time on patrol duties.

(4) Reduction is possible in the number of gangmen.
(5) Results are more uniform, particularly due to specialisation.
(6) Major repairs can be carried out without special arrangements.
(7) Efficient mechanisation is possible.

A few minor disadvantages are :

(1) Detailed supervision cannot be given in very large gangs.
(2) A certain amount of time is lost by special gangs in moving from place to place.
(3) Special accommodation has to be provided for special gangs.
(4) Greater output is obtained with special gangs but the quality of work is likely to suffer.

With regard to mechanisation, well equipped and trained field staff for repairs to machines and a central shop for heavy repairs are essential if considerable loss of working time is to be avoided because of machine failures. It has also been found that mechanisation is not economical on single lines with heavy traffic due to the considerable time lost for passing trains.

A method of maintenance known as *detour method* has been successfully applied on double track sections. About 5 miles of one of the two tracks is closed to traffic and temporary crossovers provided at each end. About 150 men completely overhaul the section and carry out renewals of materials where necessary. A saving of over 50 per cent is claimed for this method.

1405. Method of carrying out miscellaneous works

In para 1402 it was mentioned that the strength of gangs, as given, was for normal routine work. There are many other works which are required to be done occasionally and a list of some of these is given below:

Loading materials in wagons and unloading.

Stacking materials.

Attendance at temporary signals erected for major repair works.

Repairing earthwork of banks.

Clearing noxious vegetation from yards.

Removing ash from ashpits.

Special track repairs.

For such works, temporary men are employed, unless the quantity of work is very small. Works such as repairs to earthwork, loading and unloading materials, and any other work which is capable of measurement, can also be done by contract.

If the track is to be maintained in the best possible condition, it is imperative that track maintenance men are not employed on works other than those pertaining to the track. The temptation is great to allot any odd job to such men as it saves the Inspector the trouble of arranging special men. On the other hand, the tendency to appoint extra men on the least excuse is also to be deprecated. When the work is such that it is best carried out by experienced men, section gangs may be employed. The time thus lost for track maintenance may then be made up by appointing temporary men for maintenance work. Far better results are obtained by forming special gangs of such temporary men than distributing them amongst several gangs.

1406. Method of track inspection

For the safe running of trains as well as for efficient maintenance, every foot of the track is inspected daily. This work is carried out by one man in each section gang. This man, variously known as *Day line guard*, *Day patrol* or *Keyman* walks through the whole length of his section. He carries with him a few essential tools such as a spanner and a hammer for tightening loose fittings. He reports the results of his inspection to the gang mate. If any part of the track needs immediate attention, the gang proceeds at once to the spot and does the necessary work. The gang mate is primarily responsible for keeping his section in a satisfactory condition and it is desirable that the mate should walk through his section periodically, say twice a week. The keyman, who is nominally the mate's assistant, should look after the gang whilst the mate is away. This also gives good training to the keyman for the mate's post.

Inspectors and Sub-Inspectors inspect the whole length of track in their charge frequently. Such inspections are carried out in a trolly and the entire length is covered at least two to three times a week. Notes are made of the places requiring attention. The mileage and the number painted on telegraph posts adjoining the track are invaluable in identifying the exact spot by the gang mate.

Almost all defects can be picked out from the trolly, provided the Inspector is on the alert. Loose fittings, low joints, sags, kinks

and defects in alignment are easily recognised. It is not so easy to locate, from a trolly, defects in cross levels or gauge. Frequent stops should be made and both these items checked. The seat on the trolly should be kept as low as possible since defects in surface and alignment can be picked out more easily from a low seat. Inspection by trolly should not, however, be considered sufficient. It is very necessary to inspect the track frequently from a train at speed. Invisible voids and sags can only be detected in this way and all other defects will be easily spotted. Each type of defect causes a particular movement in the vehicle and with a little experience, each defect is easily recognised. When inspecting from an engine, the best position for observing defects is the *tender*. As the heavy front portion is attached to the tender with couplings, but is otherwise entirely separate, all movements of the front portion of the engine are distinctly noticed from the tender. Track defects may also be noticed from the last vehicle on a train but the defects are not felt as distinctly as from the far heavier engine.

If the type of defect is noted down in full, sufficient time is not available for recording all defects, particularly on a poor track. Symbols may be used for each type of defect and the only items to record for each defect is the mile and telegraph post number and the symbol. The symbols used by the author are given in Fig. 1406.

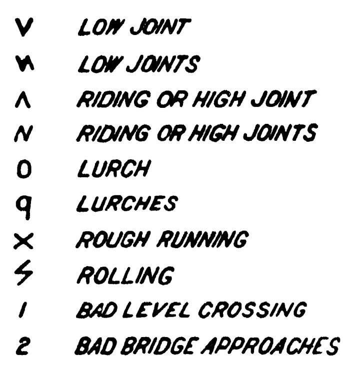


Fig. 1406

An inspection by engine, if it is to be of any value, should be followed up as soon as possible, by trolly inspection and the cause of each defect noted on the engine, investigated. The section gangs should also be given the list of defects for immediate attention.

During trolly inspections, the work already done should also be inspected in detail to see that it is properly carried out. If any defects in the work done are noticed, these should be rectified.

Inspection of track on foot is the only satisfactory method in congested yards. Very little is missed if one is on the alert. This method is recommended for through lines also, particularly those with heavy traffic. Supervising staff should also inspect their whole length periodically on foot to enable a very detailed inspection to be carried out.

1407. Primary records of track maintenance

It is not possible to remember all the defects found at an inspection and notes should therefore be kept of the defects. Even if a defect is small, it should be entered in the note book. When the same section is inspected again, the previous notes should be consulted to see if the defects noted on the former inspection have been rectified. If a special note book is maintained, with a page for each mile, and observation at each inspection entered on the particular page for each mile, an automatic record is obtained of the behaviour of the track from mile to mile. This is a great advantage, not only in deciding if any special steps are required on any particular portion, but also in checking the quality of work done by the section gangs.

The same book, or another note book, should contain for ready reference, full details of the mileages of stations, bridges, culverts, level crossings, lengths of cuttings and banks, curves, grades, types of track fittings, numbers of loops, sidings, points and crossings in yards, position of main signals, capacity of overhead tanks, position of pipe lines, water columns, district and state boundaries, and any other details.

Records are also necessary to show when surfacing, screening, ballasting, etc., of the track is done, as well as details of through renewals. Such records are necessary for the efficient maintenance of track, inasmuch as they help to decide on the action required from time to time, to keep it in good fettle. The section gangs are to be given the results of inspection pertaining to their section. Verbal instructions are usually given but for greater efficiency, the mileages where defects have to be set right together with the nature of the defects should be noted down for each gang. Special note books are maintained for each gang, or such notes are made in the attendance book or muster sheet of each gang. When work is completed at any particular mileage marked in the note book,

attendance book or muster sheet, the gang mate scores out the item concerned.

Details of spot renewal should be recorded in the Inspector's note book at each inspection so that a proper record may be maintained.

An *attendance book* or *muster sheet* is kept in charge of each gang mate. The attendance of all the men is entered by the mate every morning and afternoon and frequently checked by the inspecting staff. It is useful to have the mileage, at which the gang works, entered each day at the bottom of the page. A prearranged set of letters are used to record presence, leave etc. The monthly wage bill is prepared from such attendance books or muster sheets.

Charts, either simple or elaborate, are sometimes prepared in the Divisional or Sub-Divisional Office to show the different classes of maintenance work done. They form useful records for future reference, and for various other purposes.

In some countries track maintenance work is planned on the basis of

1. Charts of track recording cars,
2. Comprehensive traffic office records,
3. Inspection notes of Track Engineers and Inspectors, and
4. Special requirements indicated by Engineers.

1408. Duties of gang mate or ganger

The gang mate is in charge of the railway property in his section and is responsible for the safety of the track entrusted to him. He controls the gangmen in his section and has all the routine maintenance of track carried out. He also sees to the tidiness of the track and yards and is in immediate charge of all renewal work. He has to inspect his whole section frequently and to take prompt action where necessary. Tools and plant of his gang are to be accounted for by him and kept in a safe place, on completion of each day's work. In rainy or stormy weather, he patrols the track with his men and takes necessary action to stop or slow down trains, if he apprehends danger and sends a report at once to his Inspector. He makes good immediately any small defect found during such patrol work. In case of floods, he posts his gangmen at danger spots. He has also often to carry out a variety of miscellaneous duties such as loading or unloading materials, repairing fences, policing his section, transporting materials on material lorries, cutting firelines where there is a prolific growth of grass

or brushwood, cutting branches of trees obstructing the clear view of signals, keeping waterways of culverts clear of obstructions, noting high flood levels at culverts and bridges, maintaining proper road surface at level crossings, etc.

As has already been pointed out, as much of the miscellaneous duties as possible should be carried out by an agency other than the section gangs otherwise the essential work, namely, the proper maintenance of the track, suffers. When work is done to a set annual programme, there is more reason to insist on this point if the work is not to fall into arrears, or if it is not to be scamped. The gang mate should not only maintain the track in good condition but he should try and improve it. He must be fully conversant with the rules applicable to him, must fully understand his responsibilities and must be a careful and reliable person He should prepare his own daily and weekly programme, to fall in line with the general instructions. He must know every detail of his section thoroughly, such as the number and location of points and crossings, bridges, level crossings, particular spots in the track giving constant trouble and various other details. The gang mate must have a thorough knowledge of the various signal aspects and should know how and where to fix temporary signals.

As a rule, work which involves any operation which might affect the safety of trains, should not be carried out by the mate in the absence of the Inspector or his assistant Examples of such operations are renewal of rails in the main track, heavy adjustments in points and crossings and transport of materials on a material lorry between stations.

In carrying out routine maintenance, the mate must follow the correct sequence of operations. If, for instance, he is doing spot surfacing, the correct sequence is to remove ballast round sleepers, adjust kinks or correct the alignment by slewing, pack under the sleepers bringing them to correct level, box the ballast and clean the cess, removing weeds from the ballast at the same time. Wrong sequence means wasted work. If, for example, slewing is done after packing, the track has to be repacked and work done in the first packing is wasted.

The gang mate must see that all tools are in serviceable condition and have them deposited in a safe place at the end of each day's work. Leaving them hidden somewhere near the track, to avoid having to carry them the next day, is a practice which may lead to trouble. He must take equal care with materials entrusted to him for renewal, particularly small fittings as these are apt to get lost easily. Wooden sleepers need special attention to prevent loss by fire, theft, decay, etc.

Working to a programme does not by itself ensure that the track will be maintained in excellent condition. The work may not be carried out as well as it should be and very much depends on the gang mate. For instance, packing done under the supervision of one mate at the same place may last longer than that done under the guidance of another mate. This aspect needs careful consideration in track maintenance.

The gang mate must personally direct all the work of his gang throughout the day. The only exception is when he goes for inspection of his length, and the keyman or the most competent gangman is then put in charge of operations.

Gauging and checking of points and crossing is an important work of the mate and should be carried out systematically and at regular intervals, so that no points are overlooked.

When special patrols are appointed during the monsoon or for any other reason, the mate should see that they are fully equipped and that they proceed on duty at the appointed hour.

If the mate apprehends any danger to the safety of trains, he must take all necessary steps to stop trains and at the same time inform his inspector and take steps to remove the danger if it is possible for him to do so. If an accident occurs, he and his gang must render every assistance. He must take immediate steps to make the track safe or prevent trains from approaching.

1409. Duties of keyman or day line guard

The keyman walks over the whole gang section at least once a day, making a detailed inspection of the track. He tightens all loose fittings such as fishbolts, spikes, sleeper keys, etc., inspects all points and crossings, and tightens anything found loose. On bridges, where sleepers are attached to the girders with hook bolts, he turns these hook bolts to the correct position before tightening. He also periodically tightens the clamp bolts fixed at the ends of sleepers as loose clamp bolts are useless. He also keeps the track tidy, attends to fences, and removes any bushes or tall grass from the top of the formation.

In rainy weather, he removes any obstruction in side drains to keep water flowing, watches floods for signs of erosion of banks or possible damage to bridges, and if any danger is apprehended, he warns drivers of approaching trains and informs his gang mate or inspector.

The keyman should carry out his inspection in the morning. He should go fully equipped with a keying hammer and bolt spanner, hand signal flags and detonators. *Detonators* are a form of audible signals. They explode with a loud report if any wheels pass over them. On double lines he should walk against the direction of traffic. On single lines he should walk along one rail and return along the other rail. He must be particularly alert in rainy weather or in storms and must, on such occasions, inspect the track as often as possible and not limit his inspection to one trip per day. After completing his inspection and reporting to his mate, he should work either with the gang, or in its vicinity, unless there is any particular work to be done at some other place. On his inspection he must keep a lookout for broken fishplates or rails.

One of the important works of a keyman is to grease fishplates and oil fishbolts. He is given one or more helpers for this work which is done usually once a year. If fittings of steel sleepers include clip bolts, these bolts have also to be oiled by him to prevent *freezing* of the nuts on the bolts.

The keyman is considered to be the assistant of the gang mate and when the latter cannot be present with his gang for any reason, the keyman takes charge.

The keyman must be conversant with the fundamental rules as far as his work is concerned.

1410. Duties of Inspectors, their Assistants and Mistries

The Inspector is responsible for maintaining the track in his section in a safe condition for passage of trains. He is also responsible for the efficient upkeep and custody of railway property in his section. He arranges to carry out all necessary work on the track through his gangs and sees that it is done efficiently and economically. He sees that the various rules and regulations, with which he must be thoroughly conversant, are faithfully observed.

The work of an inspector may be divided into (1) inspection, (2) instruction, (3) care and accountal of labour, material and tools, (4) reports, and (5) miscellaneous work.

An inspector, if he intends to maintain his section in the best possible condition, has to move up and down his section as often as possible, inspecting the section, rectifying defects and instructing his men. His inspections are invariably carried out by trolly. He observes all possible defects in the track, such as low joints,

bad alignment, kinks, irregular expansion gaps, varying gauge, sags, worn, cracked or broken track materials, defects in switches, crossings, bridges, level crossings, etc. He issues orders to his gangs for rectifying the defects and sees that this is done in a reasonable time. He tests the gatemen at level crossings periodically and ensures that they understand their duties, checks their equipment and replaces defective tools. He makes out daily or weekly programmes to which each gang has to work, such programmes being governed by the standard routine laid down by the Engineer. He observes the quality of packing, lifting, aligning, pulling back and various other operations carried out on the track. He personally supervises all important works, including renewal of defective materials, arranges additional ballast where necessary, sees that all tools are in fair condition and arranges for their repair or replacement. He sees to the tidiness of station yards, and the proper maintenance of all points and crossings, buffer stops, fouling boards, loading ramps, platforms, etc. He controls the men in his section and sees to the payment of their wages, records absence, recommends promotion, arranges leave and, in short, is responsible for the welfare of his staff.

If the Inspector wishes to obtain good results he must observe the following points.

He must be interested in his work and take pride in the condition of his section. He must spend as much time as possible on the track. His inspections must not be made to a set programme but should be irregular. Each gang should be told exactly what to do. The Inspector must have the work done according to his orders and not leave gangs to do what they like. In the latter case, the quality of the track will vary from gang to gang, depending on the efficiency, or otherwise, of the gang mate. Trollying through the section without observation is not inspection. Notes must be made and subsequent action taken on such notes.

A very important part of inspection is the verification of the work already done. It is not enough to order the section gang to rectify certain defects or to carry out a certain work. The portion of the work which is completed should be tested to see that it is satisfactory. The best way of giving instructions to the gangs and of ensuring that they understand them is for the Inspector to remain for some time with each section gang, give instructions, watch the work being done, correct any errors and show the men improved methods of work. Time spent with section gangs is well repaid. Gang mates should be encouraged to offer suggestions. Inspection from a trolly is not enough. Inspection from an engine and on foot as explained in para 1406 are essential.

Apart from the normal inspection, detailed periodical inspection of the following items should be carried out. All bridges and culverts should be thoroughly inspected for any defects immediately after the end of the monsoon and once again after all repair work is completed. Bridge sleepers, girders, and girder bearings need frequent inspection and adjustment. The inspection of points and crossings must be made systematically in each yard. The gauge, the curvature, the condition of materials, the packing, the levels, etc., should all be observed in detail and defects corrected. All sidings in yards should be opened out once or twice a year and thoroughly packed. All level crossings should be dealt with similarly, the rails being given a protecting coat of tar. The slopes of banks and cuttings, particularly rock cuttings with steep sides, need periodic inspection. Additional earth has to be added to make good erosion or subsidence of banks and the slopes of cuttings have sometimes to be made less steep to prevent slipping in rainy weather.

Special precautions have to be taken in rainy or stormy weather. The Inspector should trolly over his section immediately after heavy rain and even during such rain, get his gangs to patrol the respective lengths and post special patrols at points where, from previous experience, trouble is apprehended. The side drains and catch water drains should be kept clear of obstructions and silt should be removed to ensure free flow of water. Prompt action should be taken in case of an anticipated breach due to floods or in case of an accident.

Primary records in connection with track maintenance have been explained in para 1407. In addition to these, the Inspector has to maintain a careful record of materials and tools in his charge. Work is considerably simplified and correctness of such records ensured, if all materials received or issued are recorded daily. Monthly accounts are made up from such daily records. Considerable quantities of materials, such as oil, collectively known as consumable materials, are used in each section. Unless carefully checked, considerable wastage is possible with such materials.

Imprest materials are only to be used in case of emergency and the materials used are to be promptly recouped. Large quantities of track material, particularly fittings, are required for renewals. The Inspector has not only to keep a correct account but has to ensure that the materials are promptly put into the track and not allowed to lie about at stations, gate lodges and other convenient places.

The Inspector has to send periodically, certain reports and statements of materials and labour. Such reports and statements vary with different railways. Promptness in sending such reports and care in their correct compilations save a great deal of subsequent correspondence and work.

The duties of an Assistant Sub-Inspector do not differ much from those of an Inspector except that he has less responsibilities and, as a rule, has to prepare fewer records. On some railways, the Sub-Inspector is given charge of a length of the Inspector's section, whilst on other railways he acts as an assistant and works wherever required in the Inspector's length.

A Mistry helps the Inspector, or Sub-Inspector, at large or special, works and is usually selected from the most promising gang mates.

1411. Duties of Maintenance Engineers

A railway Maintenance Engineer is in charge of tracks with their formation, signals, bridges, buildings, and all other structures, roads, water supply, sanitation, land, etc. He has, amongst other duties, to inspect the tracks periodically and to see that they are kept in the best possible condition. He has to issue instructions, guide his Inspectors, arrange supply of track materials for renewal, make out programmes of renewal of materials and ballast, have banks, cuttings and bridges repaired, sanction additional labour for special works, see to the payment, welfare and discipline of all staff working in his Division, maintain accounts of labour and stores, and take prompt action in case of accidents.

The remarks given in para 1410 in connection with inspection of track by Inspectors are equally applicable to the Engineer. Frequent inspections and careful observations go a long way in keeping the track in the best possible condition. The Engineer advises and helps his Inspectors and tackles all difficult problems. When out on inspection, he checks the attendance books of gangs, periodically checks tools and track materials, and tests the quality of work done by the gangs. He has also to make a detailed inspection of all bridges, culverts and tunnels, at least once a year and have necessary repairs carried out. He has to see to the systematic inspection of all points and crossings and numerous other appliances in station yards. He has to correct and improve the alignment of curves, the calculations being worked out by him if necessary. At accidents, he has not only to make the track fit for use in the shortest time possible, but has also to make minute observation for investigating the cause of the accident. When

trouble is anticipated, e.g. some portion of track is threatened by floods, he has to proceed immediately to the spot and take all possible steps to avert the danger. This is only a brief outline of the duties of an Engineer in connection with the track and it is not necessary here to go into further details.

1412. Aids to inspection

The extent of repairs and maintenance is generally determined by experience, particularly of local conditions, a systematic examination of the track, and the appearance of defects.

The above method has shortcomings which are considerably reduced through machines which detect as well as record defects. Some instruments such as the *Hallade Track Recorder* detect common faults in a track whilst others such as the *Sperey Transverse Rail Fissure Detector* record special defects. *Dynamometer cars* containing a large variety of measuring and recording instruments are invaluable for testing the working conditions of locomotives and vehicles. Some devices not only record track defects but also mark the track with some colour where defects are found. The most elaborate records of track defects are obtained in *Track Recording Cars* used in India.

Other elaborate recorders of track defects are the *Mauzin Track Inspection* car used in France and the *Amsler Coach* in vogue in Switzerland.

The fault detectors mentioned above contain elaborate and delicate instruments, but simpler instruments also exist. An example of this is *Gurney's Recorder*. This instrument records the variation in gauge and in cross levels. It consists of a trolly on which a pendulum, to record rolls, and a few other accessories are fitted. The defects in the level of the track are picked out by the movement of the pendulum. Variations in gauge are found by the relative movement of the two wheels on one axle, the flanges of the wheels being kept in contact with the sides of the rails by means of springs.

A simple rail flaw detector operated manually and employing ultrasonic means of detection are the *Audigage Rail Flaw Detector* and the *Matisa-Sonirail Flaw Detector*. A searching unit consisting of a quartz crystal is moved over the rail joint and ultrasonic waves are passed through the rail. Variations in the pitch or tone of the instrument as obtained in headphones identify a flaw and the type of flaw.

Other simple recorders are the *Iezzi* and the *Pollack* in Italy, the *Matisa* in West Africa and a French Railways light machine hauled by a trolly.

The instrument in most common use, not only in India but also in many other countries, is the *Hallade Track Recorder* (Fig. 1412*a*).

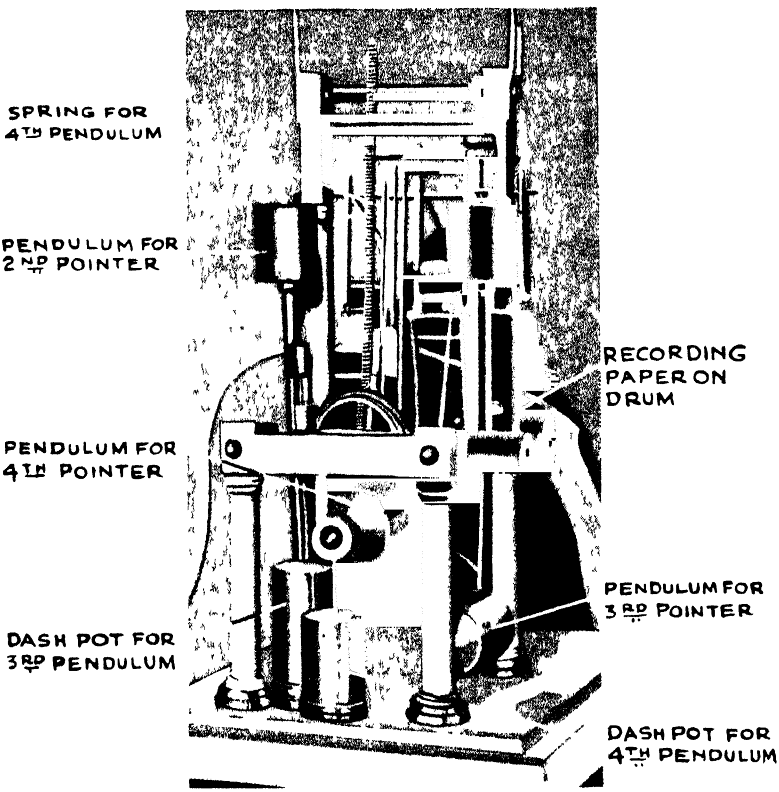


Fig. 1412*a*

It is a very compact device, contained in a portable box, measuring about 1′-6″ × 1′-6″ × 2′ and requires only two operators to work it. It can be placed in any vehicle of a train for recording purposes. It is, however, advisable to place it in one particular place in the same vehicle for all tests so that the records are not complicated by the varying characteristics, particularly as regards springs, of different vehicles.

The instrument records vertical movements, side thrusts and the rolling of a vehicle. All track defects can be found from these three movements, each type of defect has a particular effect on the vehicle. Pendulums are fixed in various positions, so that each is sensitive to movement in one direction only.

A pendulum takes up a vertical position due to gravity. If it is affected by other forces, it is displaced from its normal position and starts to swing. The amplitude of the swing is a measure of the force applied. The swing of the pendulum is recorded on graph paper which is attached to a rotating drum. The drum is made to rotate at a fixed speed by clockwork. The swings of the pendulum are damped down, with the help of dash pots or dampers, as the pendulum is very sensitive to all movements.

Four graphs are traced on the recording paper by four separate pens. The first is connected to a pneumatic plunger. It normally traces a straight line but when the position of mile posts, telegraph posts, bridges, stations, etc. have to be marked, the operator works the plunger and the pen traces a V-shaped mark. Different numbers of Vs are used for indicating different items. The location of the defects traced by the three remaining pens is easily identified by these marks. The speed of the train at every mile is also obtained from this line. If the paper on the drum is moved, say, at the rate of 8″ per minute and if the distance between two mile posts as marked by the first pointer is also 8″, then obviously the train is moving at a rate of 1 mile per minute or 60 miles an hour. If the distance between the mile posts on paper is, say, 12″, then the speed is $\frac{60 \times 8}{12}$ or 40 miles per hour.

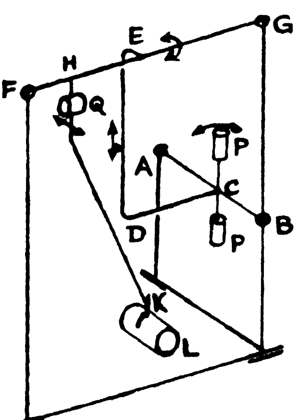


Fig. 1412*b*

The second pointer K (Fig. 1412*b*) is connected to pendulums PP and Q. AB is parallel to the track. The rolling of the vehicle from side to side cause the pendulum PP to swing at right angles to the track as shown by arrows. This imparts a horizontal movement to CD, which is converted to a vertical movement in DE. This is again converted into a turning movement of rod FG and further into a horizontal movement of pointer K through HK. Pointer K therefore records the swings of the pendulum PP. Actually the pendulums do not swing but the vehicle rolls and with

it the recording drum L; the relative movement between the pointer and the drum is recorded. Acceleration and deceleration of the vehicle is also recorded by pointer K, through pendulum G, which is attached to arm HK and swings parallel to the track.

The third pointer K (Fig. 1412*c*) is actuated by pendulums P which swing at right angles to the track on AB. This movement is turned into a horizontal movement of pointer K through CDK. A dashpot M is provided for damping the movement of the pendulum. When the vehicle is on a curve, the pendulum P instead of remaining vertical tends to remain along the line of the resultant of its weight and the centrifugal force (*vide* para 1305). Due to the superelevation in the track, the vehicle also tilts, and if the superelevation is correct for the speed at which the vehicle is travelling, the tilt of the vehicle coincides with the tilt of the pendulum and the pointer K remains along the base line of this graph. If the tilt of the vehicle is less due to superelevation being insufficient for the speed, the pointer traces out a subsidiary base line, a little to one side of the base line and parallel to it. If the tilt of the vehicle is greater, the parallel line is traced on the opposite side of the base. The irregularities in the alignment and gauge of the track are indicated by the extent of the movement of the pointer from the main or subsidiary bases. Irregularity in curvature and variations in superelevation are also found from the record of this pointer.

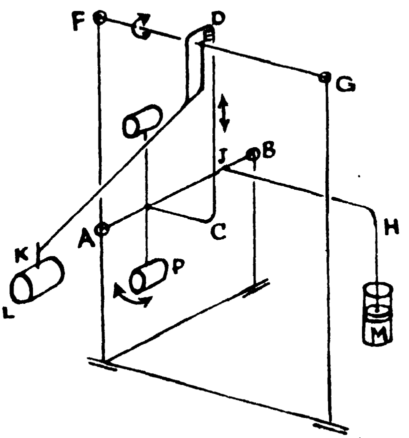


Fig. 1412*c*

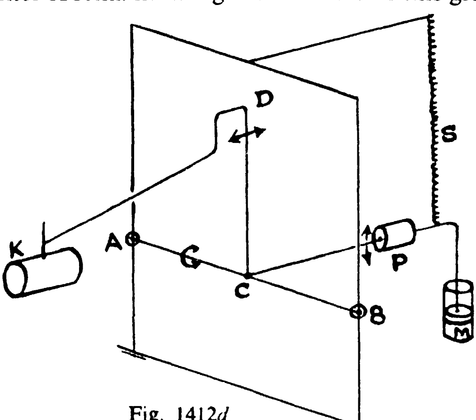


Fig. 1412*d*

The fourth pointer K (Fig. 1412*d*) records irregularities in the surface of the track. Pendulum P, which is connected to axis AB and is suspended by a spring S, imparts a horizontal movement to pointer K through CD. M is a dashpot for damping the vibrations in the pendulum.

Four lines are therefore traced on the paper (Fig. 1412*e*) and a correct interpretation of these graphs results in detailed analysis

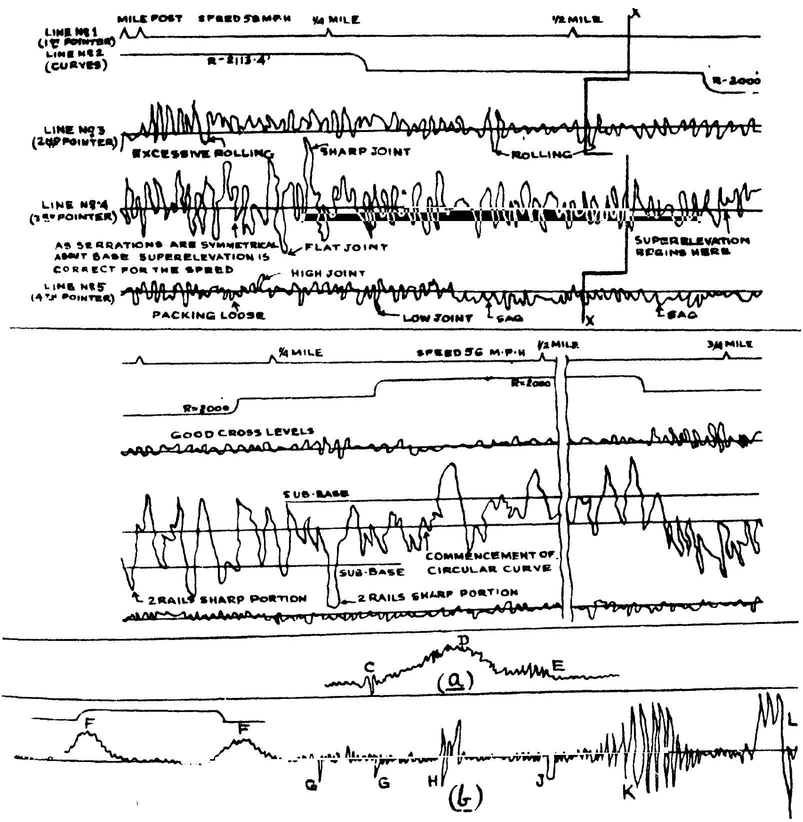


Fig. 1412*e*

of the various defects in the track, which can then be set right. A fifth line (Line No. 2, Fig. 1412*e*) is drawn afterwards to show the position of the curves so that the graph traced by the third pointer can be fully understood. The first two lines on the graph are self-explanatory. Line No. 3 indicates rolling of the vehicle

due to uneven cross levels or kinks in alignment. Excessive rolling occurs near the mile post in the example given. If the line is rounded or wedge-shaped at the apex, it indicates a severe roll.

Variations from the base in Line No. 4, on a straight track, indicate poor alignment, or variation in gauge. On a curve, variations may be due to irregularity in curvature or variation in superelevation. As already explained, since superelevation varies with speed, if the vehicle containing the Hallade Recorder travels at higher or lower speed than that for which the superelevation has been given, line No. 4 will not be symmetrical with the base line. Sub-bases have to be marked as shown in the lower half of the graph. The position of the sub-base line is obtained as follows. The actual superelevation, say 3½″, for a speed of, say, 40 miles per hour on 2,000′ radius curve, on a broad gauge track, is known. The speed, at which the vehicle containing the Hallade Track Recorder travelled over this curve, is obtained from line No. 1 as already explained. In the example, this speed is 56 miles per hour. The correct superelevation at this speed for a curve of 2000′ radius is 6½″. The superelevation is therefore short by 3″. On the graph, 1 inch represent 11.2″ of superelevation, hence 3″ superelevation is represented by 3/11.2, say 0.25″. The sub-base is therefore drawn 0.25″ from the base, and on the side of the outer rail of the curve, as the speed is higher than that for which superelevation has been given in the track.

Variations of the line from the base or sub-base means that the weight of train is being thrown from one rail to the other. This can happen if the superelevation is suddenly changed or if the curve is irregular. As it is not possible to change the superelevation suddenly, variations indicate irregularity in curvature. In the example given, the two curves of 2,000 radius each, are most irregular and require realigning. When the apex of the line is towards the inner rail of the curve, it shows that the curve is flatter, namely of a smaller degree than what it should be. If the apex is towards the outer rail, namely on the side away from the sub-base, the curve is sharper than what it should be. The variation in the degree of curve can be computed by the method given for fixing the sub-base.

Line No. 5 indicates low joints, high joints, sags and humps. Low joints are indicated by sudden dips of the line, high joints by sudden rises of line. Humps are indicated by the lines remaining a little above the base for a short distance and sags by the line being below the base for a short length. Loose packing is indicated by the line becoming thick. Small variations are due to movement of the springs of the vehicles and are to be ignored.

It should be noted that the position of the defects found in lines Nos. 3, 4 and 5 is not obtained by drawing a vertical to line No. 1. The exact position is obtained by means of a staggered line as shown at XX on Fig. 1412*e*. The staggering of the line is due to the pointers on the drum being staggered. A staggered line marked on a piece of celluloid, or obtained by bending a piece of wire to the required shape, is necessary for correct interpretation of the graph.

To facilitate interpretation of the graph, the significance of the various shapes assumed by the lines are illustrated in Fig. 1412*e* (*a*) and (*b*).

Line No. 3 sloping upward [CD in Fig. 1412*e* (*a*)] indicates slowing down of the train. A downward slope [DE in Fig. 1412*e* (*a*)] indicates acceleration.

Humps in line No. 4, at ends of curves, as shown at F in Fig. 1412*e* (*b*), mean that the curve has no transitions (*vide* para 1311), and that superelevation exists on the straight. A sudden drop in this line as at G, is due to a lurch caused by a kink. If the line, after a sudden drop, has a sudden rise, as shown at H, it indicates a double lurch due to bad gauge. If there is a sunk rail or a reverse kink, it appears as at J. A series of serrations increasing and fading away, as at K, is due to hunting of the vehicle and does not mean any defect in the track. Violent displacement, as at L, over a turnout shows that the vehicle passed over the turnout at too high a speed.

Serrations in line No. 5 similar to those at K in line No. 4 [Fig. 1412 (*b*)], are due to oscillations of the vehicle at its "critical" speed and do not indicate any defect in the track.

Hallade records are strictly comparable if the instrument is placed in the same carriage to overcome vehicle characteristics and if the carriage is run at the same speed.

The *Track Recording Car* not only detects and records various defects but also gives visual and audible indications of the various defects and automatically marks with colour wash the track where the defect is found. The position of the colour wash relative to the rails indicates the type of defect. Variations in Hallade records caused by (1) defects in vehicles and (2) variations in the action of springs of different vehicles in which a Hallade Recorder is placed are also eliminated.

The defects detected and the methods employed for detecting them are briefly as follows:—

(1) Low joints are detected by a contrivance which depends for its action on the relative movement caused between

the axle box and the bogie when the vehicle passes over a low joint.

(2) Lateral movement of the vehicle due to faulty alignment, variation in gauge, and faulty curvature, may not be perceptible when gradual but where this movement is at a rate greater than 3 inches per second, it is uncomfortable. The method employed for detection is to make the movement generate a small electric current which actuates the recording gear.

(3) The actual curvature of a curve, which may not be uniform if defective, is obtained from the angular deflection between the centre lines of the bogie and the vehicle when traversing a curve.

(4) The transverse level detector for obtaining the difference in level of the two rails is based on the difference in level caused between two columns of mercury due to alterations in the cross level of the vehicle. This difference in levels in the mercury columns moves a beam which varies the current in an electric circuit.

To cater for superelevation, which is equal to $\frac{V^2G}{1.25R}$, the detector is controlled by two additional coils. Each of these two coils receives its energy from circuits governed by the speed V of the vehicle and the radius R of the curve traversed by the vehicle. The speed circuit is energised by a generator driven from an axle of the vehicle. The radius circuit is controlled by the angular deflection of the bogie in the curvature detector.

(5) The gauge detector for indicating any variation in gauge is worked by the relative movement of two electromagnets suspended above the rails. Variation in gauge results in a relative variation in the position of the magnets. This variation affects an electro-magnetically balanced circuit and a record of this variation is obtained.

(6) The vertical movement detector for recording depressions or high spot in the track is worked by the relative vertical movement between the body of the vehicle and the bogie.

(7) The speed is recorded accurately by an electric circuit in which a powerful current is energised every 15 seconds. This current punctures the recording paper. As the recording paper is moved at 8 inches per mile by means

of a connection with the axle, the distance between the punctured holes is a direct measure of the speed.

(8) The marking of the defects in the track with colour wash is carried out by forcing colour wash with compressed air and actuating electrically the valve governing the openings.

(9) An electric printing machine produces copies of the graphs rapidly.

With the *Mauzine Track Inspection Car*, records are obtained of the relative levels of the rails, variation in superelevation, and variations in gauge and in the degree of curvature.

1413. Reduction in speed; temporary signalling for track repairs

A portion of a track may become defective or weak but need not necessarily become unsafe. In such cases, although the track may be unsafe for trains at normal speed, it may be quite safe to allow trains at lower speed. By reducing speed, the impact is reduced and results of any defect or weakness are minimised. The speed limit depends on the condition of the track. When a new track is opened, when rails and sleepers have been renewed wholesale, when the track has been through screened, when repairs are in progress or have been carried out after an accident or damage by floods or storms, in short, whenever the track bed is not thoroughly consolidated, a speed restriction is desirable. The duration of such restrictions depends on the time required for thorough consolidation. When Inspectors and Engineers feel doubtful about the strength of any portion of track they should not hesitate to impose a speed restriction, but they must not rush into restrictions on the least pretext and should foresee and take suitable steps to avoid them. It must be remembered that speed restrictions reflect adversely on the efficiency of the staff. Restrictions are also liable to disorganise traffic and every effort should be made to avoid them and, where unavoidable, to reduce their number and duration.

When restrictions are imposed, temporary signals have to be exhibited over the affected length. These may be of two kinds. When the duration of the restriction is very short, e.g., when renewing a rail, appropriate flags are exhibited. If the restriction is to last a number of days and nights, signals of the semaphore or fixed indication types are set up, and suitable lights are shown at night. In setting up such signals, the chief point to remember is

to fix them at an adequate distance to enable a train at full speed to stop or slow down, as required, at the required spot.

In addition to visible signals, audible signals must also be fixed. These invariably consist of flat circular containers with suitable explosives. They are fixed on top of rails and explode with a loud report when a wheel passes over them. They are variously known as *detonators*, *fog signals* and *torpedoes*. No one should be allowed to remain very close to detonators, when they explode, as flying fragments have been known to injure people. All railways have a complete set of rules for ensuring the safety of trains as well as of the workmen on the track. If accidents are to be avoided, those connected with the track and the running of trains must be thoroughly acquainted with the rules and must follow them strictly.

In order to avoid detention to trains and disorganisation of traffic whenever speed restrictions are imposed, this is done in consultation with those responsible for the running of trains. In an emergency, an Engineer or Inspector is at liberty to impose restrictions without such consultation.

For the safety of gangmen working on the track, a special man is kept on the look-out for approaching trains and warns the gangmen in time. Such look-out men are essential for busy sections and in locations where, on account of curves, cuttings, grades or any other reasons, the view of an approaching train is restricted. On sections with few trains, the gang mate acts as a look-out man.

1414. Recent trends

A recent trend in most countries is to replace haphazard maintenance by a systematic method. This method may be divided broadly into (1) Complete overhaul, (2) General overhaul, (3) Partial repairs, (4) Attending to bad spots. The cycle of operations varies from two years in some countries to six years in other countries.

Conservation and rehabilitation of materials is favoured such as

(1) Welding of rail joints, the rails being cropped if badly hogged.

(2) Inserting shims with fishplates or reconditioning them by restamping.

(3) Binding ends of split wooden sleepers, replugging and redrilling holes and providing bearing plates.

(4) Screening of track more frequently for drainage purposes and at longer intervals for overhauling track.

For large lifts of track, mechanical tamping, preferably with tamping machines, is adoptod. For small lifts, measured shovel packing has been found to give the best results provided the staff employed is skilled and carry out the work conscientiously.

Realignment of curve by the versine method (para 1313) is becoming a standard feature of maintenance and calculating machines are being increasingly used.

Maintenance programmes are becoming regular features and the checking of the output is carried out by graphs and tables.

The tendency for larger gangs with longer lengths and specialised gangs with mechanical tools is on the increase.

1415. Mechanised maintenance of track

Mechanisation of maintenance of track has been developing gradually with a view to effecting economy and reducing manpower. On the American railways the value of mechanised equipment per 1,000 miles of track is as much as Rs. 47 lakhs whilst that on British railways is about Rs. 5 lakhs.

It is considered that for the same cost, the amount of work done by mechanical methods is theoretically about 100 times that by manual methods. On railways, the two chief reasons militating against the increased use of mechanical equipment are (1) the necessity of transporting equipment over long distances resulting in reduced useful operation time and (2) the difficulty of obtaining occupation of the track for maintenance purposes for any lengths of time, again resulting in considerable increase of idle time.

Two types of mechanical equipment can be used. The *Off-track equipment* which does not run on the track but moves on the side of the track. Such equipment is feasible only where some sort of a service road is possible adjoining the track. The advantage of such equipment is that it remains clear of the track and track occupation for maintenance purposes is either not necessary or the period of occupation is small.

The *on-track machine*, on the other hand, requires long periods of occupation to be economical but it can be used on any part of the track.

The number of tracks and the density of traffic have a considerable bearing on the extent to which mechanical equipment can be used advantageously. With multiple tracks, particularly where traffic movement in both directions is permitted on each track, maximum advantage can be obtained with on-track equipment.

On the other hand, where density of traffic is very high off-track equipment is the only type of equipment which is economical. If off-track equipment cannot be used, manual or semi-mechanical equipment is more economical.

For the efficient use of mechanical maintenance equipment programming of all maintenance work is a prerequisite.

CHAPTER 15

Renewal and Improvement of Track

1501. Relaying track

A TRACK has to be relaid when the materials in the track are worn out, or if a heavier track is required to replace a lighter track, in order to take increased axle loads, or if the old but serviceable

material in a main line is to be replaced by new material and the released material is to be used for a branch line.

There are several methods of relaying a track, each one of which has its special advantages and shortcomings. The selection of the method for any particular work depends on the local conditions, on the plant available, the density of traffic, and various other factors. On a multiple track, perhaps the best way, if the condition of traffic permits, is to divert all trains from the track to be relayed, and open out the existing track for relaying. For the diversion of traffic, temporary crossovers, between the track to be relayed and the adjoining track, may be installed.

On a single line of track, materials may be distributed along the existing track and short lengths relayed in the periods available between trains. Each period may be of several hours duration or of even less than an hour, depending on the frequency of train service. When traffic is very heavy in the day, as on suburban sections, relaying may be done with advantage at night.

Sometimes lengths of new rails are fished together alongside the existing rails and whole lengths put in at a time, after removing the old rails. This method is rapid and is particularly useful if rails only are to be renewed.

Another method in vogue in Britain is to remove the ballast upto the bottom of the sleepers, lift up each panel of the old track with jacks and slip new rails on their sides under the sleepers. The panel is slid longitudinally on these new rails to a ramp where small flanged wheels are attached to the rails of the dismantled panel. A number of dismantled panels are strung together and hauled over the existing track to any distance for dismantling.

There are several other methods of relaying, such as: (1) Diverting the existing track by a few inches and interlacing the new track with the existing track. (2) Interlacing new sleepers only with the existing track and subsequently renewing the rails. (3) Renewing rails and sleepers in two entirely independent operations, the new rails being fixed in the first instance to the old sleepers.

In Britain, and particularly in America, mechanical appliances are used for relaying. In Britain, with the track laying machine mentioned in para 1001, complete panels of tracks are removed and new built up panels laid. In America, cranes of various designs and capacity are used both on single and multiple tracks. The jib of these cranes is long enough to remove and lay a rail length ahead of the crane track. Loading and unloading of

materials is also done with these cranes. Various other power appliances, for pulling and driving spikes, opening and tightening fishbolts, etc., are also used.

In Japan a very simple rail replacing machine is used. The machine consists of a frame with horizontal rollers, one pair above and another below the frame and also vertical rollers for travelling. The frame is pulled by a motor trolley of adequate capacity. The horizontal rollers are capable of bringing together or forcing apart a pair of rails joined together with fishplates but unconnected with sleepers.

When rails are to be renewed, new rails are deposited outside the running rails and connected with fishplates. The running rails are disconnected from the sleepers. The machine is introduced and at the starting point old rails are disconnected and new rails joined up. The new rails are placed between the lower horizontal rollers and the old rails outside the upper rollers. The machine is then pulled and in its movement forces the new rails to their approximate positions on the sleepers and pushes out the old rails to the edge of the sleepers. Various permutations are also possible in the positioning of the new as well as the old rails with this machine.

When welded rails are used, they are transported to the site on old bogie flat wagons fitted with rollers. Special clamps are provided on the middle wagon to hold the rails in position and rollers on each wagon permit the rails to move as required when the wagons go over a curve. The tiers of rails are separated by steel straps, turned up at the ends, and bolted together to form frames. A chute is attached to the head stock of the trailing wagon when unloading and a hook at the end of a chain fixed to the track is threaded through the fishbolt hole of the rail to be unloaded. The train is then pulled forward. Rails 1,600′ long have been unloaded by this method.

It must be appreciated that complete simultaneous renewal of ballast, sleepers, and rails is more economical than piecemeal renewal or replacement.

Quicker results are obtained if the new track is prefabricated in panels at suitable depots, brought to site in wagons and unloaded. No elaborate equipment is necessary. A gantry at the depot is used for loading the panels into open wagons which are provided with two rails fixed to the floor. Unloading is carried out at site by sliding the panels over a ramp made by hooking two rails to the end wagon and pulling the panels manually. To facilitate this operation the

end wagon has the least number of panels, say three, and each subsequent wagon has one more panel than the previous one. One panel is pulled off from each wagon, the train is then backed and the operation repeated. The rails of all panels as well as the rails fixed to wagon floor are greased at the time of loading to facilitate their unloading. The unloaded panels are connected together, aligned and packed, the old track having been dismantled in short lengths before the unloading of each group of panels. Additional ballast is also carried on the relaying train in wagons behind the engine (the track panel wagons being in front of the engine), and unloaded over the relayed track.

1502. Standard method of relaying in India

A detailed description of the method of relaying during short intervals between trains, which is commonly used in India is given below. As in linking new tracks, thorough organisation is essential if relaying is to be done satisfactorily. The work may be divided into three phases : (1) preliminary work, (2) actual relaying, and (3) consolidation of relayed track and removal of released material. The progress in the second phase depends considerably on the thoroughness of the preliminary work, including attention to minute details. The new material is first sorted in one or more depots and the rails and sleepers are distributed along the track.

The rails are unloaded in lots at certain distances and distributed with the help of material lorries or Anderson rail carriers. Material lorries are also used for the distribution of sleepers; the rails being deposited in such a way that they do not have to be pulled in the direction of the track to fit in their correct position in the track.

It is advisable to distribute the rails and sleepers along one shoulder of the cess only and not along both shoulders. The sleepers are often distributed on the slope of banks and cuttings and at right angles to the track. It is easier and quicker to pick them up when distributed in this way. Sleepers may also be kept on the shoulder of the cess and parallel to the track but this method is not very convenient unless the cess is wide. Fittings are not distributed beforehand. Immediately ahead of the relaying work, two out of four bolts at each joint are removed and the remaining two oiled; spikes or other sleeper fittings are removed from alternate sleepers. The ballast is removed from the cribs to a level a little below the bottom of the sleepers, screened and kept along the shoulder of the cess, opposite to that on which materials are

distributed. The ballast may not be screened if it is fairly clean. Centre line pegs are fixed at intervals by measuring from one or other of the rails with the help of a mark at the centre of a track gauge. In the second phase, the rails and sleepers are removed, after necessary signals are exhibited. Each gang is allotted a certain number of rail lengths, the number depending on the time available between trains. The rails are removed and placed on the shoulder of the cess. The released sleepers are thrown on the formation slope. The ballast in the track bed is then levelled and new sleepers placed in position. One line of rails is then laid and fished together, only two out of four bolts being used. The spacing of sleepers is then marked on the rails, the sleepers brought to their correct position and the rail fixed to alternate sleepers with appropriate fittings. The second or gauge rail is then laid and fixed, also to alternate sleepers and to correct gauge, after the joints are squared. The track is slewed to the correct alignment and those sleepers to which the rails are fixed are packed. The remaining fishbolts are then inserted and the fittings on the remaining sleepers tightened. The whole track is then packed. The ballast previously removed and deposited by the side of the track is used for packing. The reason for dealing with half the number of sleepers at a time, is to enable a train to pass at restricted speed even if the whole operation is not completed when the train arrives.

The track is subsequently thoroughly packed for a second and a third time, additional ballast being supplied from a ballast train. The released rails and sleepers are picked up with a material train or the empty ballast train. The rails are collected at suitable intervals with material lorries or Anderson carriers to facilitate loading in rail trucks attached to the ballast or material train. A speed restriction is maintained over the relaid section until the track is thoroughly consolidated, and the period of this restriction is kept as small as possible.

1503. Some data regarding relaying work

The number of men required for relaying depends on the progress per day contemplated and on the blocks or periods available between trains. About 300 to 350 men may be considered sufficient for relaying from $\frac{1}{4}$ to $\frac{1}{3}$ mile of track per day of broad gauge track and 250 to 300 men for relaying a similar length of metre gauge track. This number includes the men required for packing the relaid track, but excludes men working on material trains. About 75 to 100 men are required for loading and un-

loading material trains. Following is an approximate distribution of labour for relaying metre gauge track.

1.	Removing two fishbolts from each joint, removing spikes or other fittings from alternate sleepers and removing ballast from cribs to a depth of 2″ below the bottom of sleeper. (If screening is to be done, additional men are required)	40 men
2.	Distributing correct quantities of new materials along the track, and fixing centre line pegs ..	20 men
3.	Actual relaying	100 men
4.	Through packing and boxing	60 men
5.	Miscellaneous works connected with actual relaying work, such as fixing closures, signalmen, men for distributing fittings, men on trolleys, men with artisans, e.g., blacksmiths, carpenters, etc.	30 men
6.	Sorting and stacking released material for picking up by material train, ...	20 men
7.	Allowance of about 5% for sickness, absence and unforeseen items of work	15 men
	Total	285 men
	with	12 mates

The following figures are given for relaying a broad gauge single-line track. In this particular case, the same rails were used, but wooden sleepers were replaced with steel trough sleepers. A block of three hours was available daily, and ¼ mile was relayed in this period. The labour employed consisted of 350 men, including men for final packing. All preliminary work was done by these men. Ballast was not boxed for some weeks after relaying, namely, until the track had thoroughly settled. The distribution of men for the three phases of work and a complete list of tools are given below.

Group	Work done by each Group during the preliminary period	Block period	Post-block period	Number of men	List of tools used
1	Removing two fish-bolts; Oiling all fishbolts ahead of relaying work	Removing two fishbolts and re-fixing all fish-bolts	Tightening fish-bolts	15	12 fishbolt spanners 12 chisels 3 claw bars 1 tommy bar 1 punch 4 oil containers

Group	Work done by each Group during the preliminary period	Block period	Post-block period	Number of men	List of tools used
2	Removing spikes from the gauge side of alternate sleepers	Removing spikes from the gauge side of remaining sleepers	Removing the remaining spikes from released sleepers, collecting fittings, packing track	15	12 claw bars 12 beaters 4 shovels 4 steel baskets 2 ballast forks
3		Removing rails from track, marking position of sleepers on rails	Packing track	12	8 beaters 4 claw bars 2 tommy bars 2 shovels 1 track square chalk
4		Removing wooden sleepers from track	Sorting and stacking sleepers, packing track	25	20 beaters 2 claw bars 5 shovels chalk
5			Dressing ballast, packing track	25	20 beaters 10 shovels 4 claw bars 2 ballast forks
6		Laying new sleepers	Packing track	35	30 beaters 15 shovels 10 crow bars 2 spirit levels 2 straight edges 1 track square 4 ballast forks Expansion liners
7	Marking centres of sleepers, fixing pegs on centre line of track	Adjusting sleepers with regard to the centre line by stretching strings between centre line pegs	Packing track	10	10 beaters 8 mallets 5 centre line templates 2 spirit levels bamboo pegs string or fishing cord
8		Replacing rails, slewing track	Tightening clip bolts, slewing track	15	8 box spanners 10 crow bars
9		Replacing sleepers to correct position	Packing track	10	8 beaters 6 crow bars 2 shovels 2 hammers
10		Fixing clips correctly and tightening clip bolts	Tightening clip bolts	60	50 long spanners 8 tommy bars 15 claw bars 15 hammers 15 box spanners
11		Putting back ballast	Putting back ballast and packing		10 steel beaters 10 steel baskets 20 ballast forks 10 shovels
12	Removing ballast from track ahead of relaying			40	30 ballast forks 15 shovels 20 steel baskets
13			Second packing	40	40 beaters 10 crow bars 10 ballast forks 10 steel baskets
14	Flagmen and signalmen			12	Flags Detonators Lamps
15	Allowance of about 5% for sickness, absence and unforeseen items			16	
			Total	350	

1504. Special requirements for track with long welded rails and destressing

As indicated in para 220, tracks with long welded rails are likely to be used extensively. The laying and maintenance of such tracks, with welded rails of, say, $\frac{1}{2}$ mile length, necessitate certain requirements, omission of which would lead to trouble.

The essential requirements are as follows :—

(1) A long welded rail track should be laid on a substantial layer of ballast which should be well consolidated.

(2) The rails should be laid at a temperature which is near the annual average prevailing in the region concerned. If this is not possible, destressing should subsequently be carried out at about the annual average temperature.

(3) Packing and realigning should be done only when the temperature is within a specified range of the annual average temperature.

(4) The application of long welded rails should be limited to straight tracks and flat curves.

Other requirements are that :—

(5) Sleepers should be as heavy as possible and the fastenings should be adequate to prevent creep of rail.

(6) Intensive maintenance of the track should be carried out for some months after laying.

(7) Expansion or adjustment switches should be provided at both ends of the welded rail, unless the ends are heavily anchored for a length of about 240 ft. or more.

(8) The welding of rails both in the shop and at site (for extending welded rails to still greater lengths) should be satisfactory. The surfaces of the head of the rail should be smooth to prevent impact at these welded joints. If partly used rails are employed the rail ends which are usually slightly depressed through use, should be straightened before welding.

The minimum radii of curves suitable for long welded rails have been indicated in para 220. In France it is considered that temperature variations of as much as $+40°$ C. may be permitted on 800 m. (2,625′) radius curves compared with the temperature at which the rails were laid.

Concrete and steel sleepers with higher lateral resistance are considered more suitable than wooden sleepers, which however are also sometimes used, with special secure fastenings. With concrete sleepers, lateral strength tests in France have shown that the minimum radius of curve can be reduced to 500 m. (1,640').

The ballast should have adequate depth, adequate shoulders and should be given a uniform surface before laying of sleepers. The ballast has also to be well consolidated. In Britain a 12" depth of ballast is provided, whilst in Germany, the bottom ballast is laid and consolidated to a perfect surface, and the additional ballast is spread, vibrated and rammed, all operations being carried out mechanically. Germany also specifies ballast shoulders of 0.35 m. (115') on both straight lengths and curves and for all types of sleepers.

Creep anchors are widely but not universally considered necessary. The German railways fix them for distances of 50 m. (164') at each end of a length of long welded rail without expansion joints, mainly to ensure resistance to longitudinal movement in the rails, should the fastenings work loose in course of time. In France and Britain, expansion switches, to permit limited expansion, are provided at each end of the long welded rail. Expansion switches, in addition to taking care of temperature variations in the rail, are very useful in destressing operations.

To avoid undue expansion and contraction and the resulting serious consequences, long welded rails have to be laid within a temperature range a few degrees above and below the annual average temperature of the region. This may not always be possible and in such cases, *destressing* has to be carried out. This may be done by loosening all rail fastenings by about $\frac{1}{8}$", when suitable temperatures obtain, running a locomotive at a slow speed (about 20 m.p.h.) several times over the track and retightening the fastenings from one end. The resulting longitudinal movement of the rails is taken up by the expansion switches.

The time taken by a long welded rail to consolidate thoroughly depends largely on the speed and weight of traffic and other local conditions. Intensive maintenance is required during the first few months after relaying. In France this period is taken as 12 months. The labour employed during this period per km. (.62 mile) of track is 500 man-hours. In Belgium more intense work is done, the figures being 600 man-hours for track with wooden sleepers and 1,000 man-hours with concrete sleepers.

After the welded rail track has been thoroughly consolidated, subsequent maintenance is much lighter than with standard track.

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This is where considerable savings in maintenance, mentioned in para 220, are effected.

A welded rail track remains in good condition even with reduced maintenance for a much longer period than a standard track, with the result that the period of overhaul is increased. In Germany the increase in the overhaul period is from 3 to 5 years.

No serious trouble has been experienced with welded rail tracks. In a very few cases where buckling has taken place, this has been due to disregard of some of the requirements mentioned above, particularly temperature requirements. In most countries, mechanical tamping is employed for routine maintenance, but in some it is supplemented by shovel packing. Surfacing and realigning have to be restricted to temperatures within a limited range of the annual mean temperature. In Britain a range from 40°F to 80°F has been used. This limited range is necessary to prevent lateral movement of the track, with high locked up temperature stresses in the rails, because of reduction of lateral support.

1505. Dismantling track

It is necessary, on rare occasions, to dismantle track on branch lines where traffic is light and other forms of transport are more economical. Dismantling is also sometimes undertaken for releasing track, for use elsewhere in national emergencies. If the track is to be restored after the emergency is over, the dismantling to be done is quite simple. If, on the other hand, the branch is to be abandoned, not only is the track to be removed complete with the ballast, but all bridge girders and steel structures have to be dismantled and taken away. Masonry buildings are often sold locally. Dismantling of structures and removal of released materials are done before the track is picked up, but the girders can be dismantled only when rail-head reaches the particular bridge. The time taken in dismantling girders delays the removal of track. Before removing the rails and sleepers, the ballast in the cribs is removed and collected along the track. It is then picked up with ballast trains. Removal of ballast from the cores under sleepers, after removal of the track is not an economical proposition and usually the quantity thus lost is not very great. The simplest method of dismantling and removing the track is to keep a material train at rail head, marshalled with the rail trucks towards the rail head, followed by sleeper wagons and the engine. The material train is kept a distance away from the rail head, equal to the length of track to be dismantled in each period of the day, plus a short length for loading rails. The rails

are disconnected from sleepers and conveyed to the short length left between the portion to be dismantled and the material train. The sleepers are picked up and conveyed to the material train. The rails are loaded in the rail trucks, either manually or with some simple lifting or pulling device. The material train backs an appropriate distance and the operation is repeated. Special arrangements have to be made for loading released girders. Usually a locomotive crane is attached at the rail head end of the material train and deposits girders, either whole or in parts, in an adjoining truck. The speed of dismantling depends mainly upon organisation and the amount of attention paid to details.

1506. Requirements

Improvement of track may be divided broadly into two classes :

(1) Periodical overhaul, renewal and reconditioning of track material to bring a deteriorated track to an efficient standard for existing loads and speeds.

(2) Similar work, together with revision of gradients and flattening of sharp curves to improve the standard, to enable increased loads and speeds to be attained.

In the paragraphs that follow, a number of methods available for improving the track are given. One or several of the items may be necessary for improvement, depending on the condition of the section of track concerned.

1507. Resurfacing

The track loses its resiliency in time and also sinks slightly under the constant rolling of the loads. Resurfacing is therefore required to be done periodically. A track which has lost its resiliency causes damage to vehicles and the track need not necessarily give very rough running before such damage is caused. Surfacing consists of lifting the track on a layer of fresh ballast and through packing. The ballast cushion, which is reduced gradually due to sinkage of ballast in the formation and powdering under the sleepers, is thus returned to its normal depth, sags in the track due to sinkage are removed, and the resiliency is increased due to the introduction of a layer of clean ballast. The intervals, at which surfacing should be done, depends on so many factors that no definite period can be fixed. The amount of traffic, the quality of maintenance work, the condition of track materials, the type

and quantity of ballast, the nature of soil in the formation, all have a bearing on this period.

1508. Cleaning and renewal of ballast

The method of carrying out through screening has been explained in para 1113. It is even more effective than resurfacing in improving the resiliency of the track. It is carried out at regular intervals in America. Heavily worked lines are screened at intervals of 3 to 5 years and lines with light traffic at intervals of 5 to 8 years.

In the same para the possibilities of the Ballast Drag have been explained. The advantages of an increased depth of ballast for carrying heavier loads at higher speeds are indicated in the chapter on track stresses. Through cleaning or screening of ballast, and giving a lift to the track with additional ballast improve the condition of track considerably and may be essential where higher speeds and loads are to be introduced.

An example of ballast cleaning and renewal with other necessary operations is given below. There was heavy creep on the track and a large number of sleepers had been pulled out of position. Pulling back, squaring and respacing of sleepers was therefore done at the same time. The portion concerned was a double line section with 36′ long 90 lbs. rails on pot sleepers. In order to ascertain the quantity of additional ballast necessary, half rail lengths were screened on both up and down lines, every quarter mile and it was found that make-up ballast would be required at the rate of 3 cubic feet per foot length on the up line and $3\frac{1}{2}$ cubic feet per foot length on the down track. As the cess had to be kept clear for screening, the additional ballast was unloaded only in the space between the two tracks. To avoid congestion, only 4 out of the total $6\frac{1}{2}$ c. ft. were unloaded before the work started, the remaining $2\frac{1}{2}$ c. ft. being unloaded on completion of screening.

The work involved six distinct operations and the labour required, per rail length of 36′ of single track, for each operation was as follows:

(1) Removing anchors, loosening rail fittings and pulling back rails (1 man per 4 rail lengths).

(2) Removing loose ballast from cribs with ballast forks (1 man per 2 rail lengths).

(3) Digging mixed ballast and earth from cribs upto a depth of 12″ below sleeper level and screening the same through ballast screens placed on the cess (3 men per rail length).

(4) Breaking cores of consolidated concrete under the sleepers and screening the material. Also squaring and respacing sleepers, refixing anchors, replacing screened as well as fresh ballast and initial packing (4 men per rail length). The core was broken under every fifth sleeper, so that at any time there were 4 fully packed sleepers available for every loose sleeper. Trains could therefore be passed over the section, at restricted speed, at any time.

(5) Second through packing and picking up ballast scattered on the cess (1 man per rail length).

(6) Third through packing, picking up ballast scattered on bank slopes and dressing cess (3 men per 2 rail lengths).

As trains were frequent, only a quarter mile of track was tackled daily in order to avoid heavy detentions to trains; operation (3) was kept one day behind operation (2) and there was a similar interval of one day between operations (4) and (3). A speed restriction of five miles per hour was imposed on the half mile covered by operations (3) and (4) and a 20 miles per hour restriction on the half mile covered by operations (5) and (6). There were no speed restrictions for operations (1) and (2).

The number of men required for such work depends on the type of screening done, the quality and condition of existing ballast, the type of sleepers in the track, the amount of pulling back and respacing of sleepers necessary and other factors. This is illustrated by the following further example of work done in a single-line track with 30′ long 75 lb. rails on wooden sleepers. Regauging and adding two additional sleepers per rail length, had also to be done, but the depth of screening varied from 3″ below the bottom of sleeper at the centre to the full depth at the ends of sleepers. The operations involved and the labour required were as follows :

(1) Removing anchors, loosening rail fittings and pulling back (1 man per 2 rail lengths).

(2) Screening (8 men per 3 rail lengths).

(3) Distributing additional sleepers (1 man per 3 rail lengths).

(4) Respacing sleepers and inserting additional sleepers (2 men per rail length).

(5) Initial through packing (1 man per rail length).

(6) Second through packing (2 men per 3 rail lengths).

(7) Regauging and anchoring track (1 man per $3\frac{1}{2}$ rail lengths).

1509. Reconditioning curves and introducing transitions

Curves do not retain their correct alignment for very long periods due to the lateral forces to which they are subjected. Periodical realigning, as described in para 1313, is very necessary. Distinct improvement, in the riding qualities of a curve, is obtained by introducing transition curves at either end of a curve, if they do not already exist. Alignment pillars are invariably fixed at short intervals when a curve is realigned.

1510. Pulling back, squaring and adjusting sleepers

The evils of creep have been dealt with in para 1210. The best course is to prevent all creep by heavy anchoring. This is not always possible. Pulling back brings the rail joints to their correct position relative to the sleepers; squaring of sleepers corrects the gauge, disturbed by the pulling askew of the sleepers; adjustment of sleepers to their correct position gives an improved support to the rails.

1511. Improving crippled or hogged rails and battered rails

Under the chapter on rails. one of the serious rail defects, namely its crippling or hogging, has been mentioned. The best, but the least economical way of improving such a track is to replace the hogged rails by new ones. The usual practice on railways is to remove slightly defective rails, which are yet serviceable, from important through lines and to use them in unimportant branch lines after reconditioning. New rails are used on the through lines in place of those removed. Another method is to reroll the rails. This practice is not much in favour, as the costs are fairly high. A more economical method is to cut off short lengths at the ends of the rails, so that the bent portions may be removed, drill fresh bolt holes and reuse the rails. There are two methods of doing this work which is usually described as *cropping* of rails. In the first method, a certain number of rails are replaced by other rails and the released rails taken to a depot where they are cropped and drilled. They are then replaced in the track. This involves handling of rails on two occasions and transporting them to and from the depot. In the second method, both these drawbacks are avoided. The rails are drilled in the track with portable pneumatic drills, the rail fittings are removed, the rails are cut with power saws, pulled back over the gap left due to the shortening of the rails, and the fittings are refixed. This method has been adopted in America and the following is an example of such work. 33′ long

rails were cropped and converted to 30′ rails, and 10 full rails were replaced by 11 cropped rails. The drilling and cutting was carried out in the track by 66 men with 3 portable pneumatic drills and 8 power saws. The record number of rails drilled, cropped, pulled to their new position and refixed in a day was over 150. Rail ends have also been cut with the oxy-acetylene torch.

Worn ends are also built up by welding (*vide* para 219). This method is largely adopted in America. Portable welding and grinding sets enable the ends to be built up without removal of the rail from the track.

A simple device known as a *Dehogging machine* for removing the vertical bend from rails has been used, with success, in India. The machine consists of a bottle jack (35-ton Duff jack is suitable), a length of old rail and two sets of clamps (*vide* Fig. 1511). A 6′ long straight edge is placed on the joint and the rail is marked at a point at the commencement of the bend in the rail. The fishplates as well as sleeper fittings from two or three sleepers on either side of the joint are removed. The dehogging machine is then introduced. It has two pairs of clamps D, each pair consisting of two straps of steel with jaws to grip the head of the rail. One of the two clamps is fixed at the end F of the rail and bolts E are tightened and the bottle jack is fixed at the point where the rail bends. (The jack should not be taken beyond the centre point of the beam). The rail is then bent upward between this point and F and the hog or bend at the end is removed. The distance through which the end of the rail is bent upward by the jack is measured with a scale S. Careful measurements are necessary to avoid an upward bend in the end of the rail. It was found that with 90 lb. flat footed rails, the end of the rail had to be bent up $\frac{1}{8}''$ for every 1/32″ of hog, the first 1/32″ however required $\frac{1}{2}''$ lift. For example, if the hog was $\frac{1}{4}''$ or 8/32″ the rail end had to be lifted $\frac{1}{2}''+(7\times\frac{1}{8}'')$, namely $1\frac{3}{8}''$. The daily output was 120 rail ends or 30 panels with one mate and 18 men using one machine. It was feared that such cold bending of rails might result in rail failures, but dehogged rails have given several years' service without any trouble. A similar arrangement has been successfully

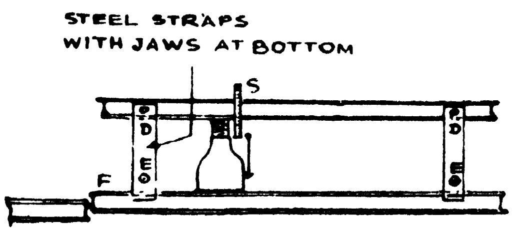


Fig. 1511

used in America, the machines being mounted on 6″ dia. double-flanged wheels. The lift given was three times the original hog or bend in the rail end.

Vertical bending of rails with dehogging machines often kinks the rail and these kinks have to be removed by a similar arrangement of bottle jack and frames but in the horizontal plane. The straight edge is laid along the running edge of the rail and the jack is fixed at the point of the kink. The screw of the jack is turned through a distance double that of the amount of kink. Sometimes a jimcrow is used instead of the bottle jack and frame, the screw of the jimcrow being fixed at the point of kink. If this point is too close to the end of the rail, so that one arm of the frame or the jimcrow has no purchase, the adjoining rail is connected with fish-plates to enable the operation to be carried out.

1512. Reconditioning rail joints by inserting shims or repressing fishplates

The contact surfaces of rails and fishplates get worn in time and three methods are available for improving a track with this defect (*vide* para 405). The worn fishplates may be replaced with new ones, they may be reconditioned, or liners, or shims, may be inserted between the contact surfaces of the rails and fishplates.

1513. Introduction of additional sleepers, respacing sleepers and regauging

The capacity of a track for carrying heavy axle loads is increased by the addition of sleepers. For example, a broad gauge track with $(n+4)$ sleepers can carry axle loads of 25 tons whilst a line with $(n+3)$ sleepers is capable of taking only $22\frac{1}{2}$ ton axle loads.

In a cast iron or steel sleeper road, the two joint sleepers are sometimes replaced with wooden sleepers, as wooden sleepers give a better rail joint. Opinions are however divided on this point; some track experts maintain that insertion of wooden sleepers breaks the uniformity of the track structure and consider them undesirable. The author's experience is that wooden sleepers at joints give a definite improvement in running and this improvement is further increased by keeping the joint sleepers very close and gradually increasing the spacing of the remaining sleepers, so that the maximum spacing lies at the centre of the rail.

In some types of sleepers, such as steel clip bolt sleepers, the gauge does not vary even after considerable service; with other

type of sleepers, variation in gauge to a greater or less extent takes place in time. The evils of varying gauge have been explained in para 1109. Correction of gauge on wooden sleepers involves plugging of old holes and reboring of new holes. Adjustment with steel sleepers having four keys is easy. Liners of varying thicknesses are necessary for adjusting steel sleepers having two keys and also with pot sleepers.

1514. Other expedients for track improvement

There are many possibilities of minor improvements of track and the extent to which such improvements are carried out, depends on the initiative of the maintenance staff.

Screening of two to four sleepers at each joint considerably improves low joints. Ballast required, when screening of joints is done, may be obtained by making a shallow depression or drain in the centre of track, this drain being subsequently filled up when ballasting of the track is done. If such drains are formed, cross drains at intervals of every few rail lengths must be provided.

Rail joints may be strengthened by spacing the joint sleepers closer, the sleepers throughout the length of the rail having to be spaced a little wider, to enable this to be done without the introduction of additional sleepers.

1515. Strengthening and improving the track for higher speeds

When increase in speed is contemplated, the standard of the track has to be raised. Improvement in the track consists of one or more works mentioned in paras 1515 to 1519, with or without the addition of one or more items mentioned in paras 1507 to 1514.

(1) Heavier rails may be necessary if the existing rails are not strong enough for the increased axle loads. The relation between sections of rails and axle loads is given in Appendix 12, item 21. The number of rail joints may also be reduced by welding. The ends of rails may also be hardened to minimise the effects of the blows, to which rail ends are subjected.

(2) The number of sleepers per rail length may be increased. The relation between number of sleepers and axle loads is given in Appendix 12, item 22. Even if the number is not increased, all worn or doubtful sleepers may be renewed. The existing sleepers may be replaced with different types of sleepers.

(3) The depth of ballast may be increased. Existing ballast has to be screened and the shortage due to screening has to be made good even in cases where additional depth of ballast is not required. The existing ballast may be replaced with ballast of a better quality, e.g. gravel by hard trap.

In connection with the above three items, it must be remembered that the rail acts as a girder between each pair of sleepers and the sleepers form compressible supports for these girders. The compressibility of the supports depends on the quality, quantity and the packing of the ballast. The stiffness of a track depends upon the combination of rails, sleepers and ballast and the emphasis must preferably be laid on the last two items, for effecting improvement. The aim should be to have clean ballast, of such depth and the sleepers at such spacing, that the pressure of the passing vehicles is distributed over the whole area of formation. This will not be the case, if the depth of ballast is insufficient or the spacing of sleepers is too wide.

(4) Bearing plates may be introduced if the track has wooden sleepers. Bearing plates with shoulders increase the lateral stiffness of the track. Bearing plates with a slight camber, in the direction of the rail, prevent rocking of sleepers due to the wave motion of the rails.

(5) A distinct improvement is effected in a track subject to creep, with the introduction of anchors or with their increase, if they already exist.

1516. Improvement of curves

Curves require the greatest attention when tracks are to be improved for high speed. Since the centrifugal force varies as the square of the speed, an increase in speed from, say, 50 miles per hour to 70 miles per hour, almost doubles the centrifugal force (since $50^2 = 2,500$ and $70^2 = 4,900$). If the track has insufficient lateral resistance, the alignment is thrown out. The type and number of sleepers has a considerable bearing on the lateral resistance of the track. The number of sleepers may be increased and a type of sleeper having a good grip on the ballast, e.g., steel trough sleeper, may be used with advantage. The quantity of ballast may also be increased, particularly on the outside of the curve.

Realigning of curves is not only desirable but essential, when an increase in speed is contemplated and this work can be carried out expeditiously with the method explained in para 1313.

Introduction of transition curves should also be considered a necessity with increased speed. No separate calculations are

necessary for this, as the calculations for realignment of curves include the provisions of transition. The length of existing transition curves may be increased so that the change becomes more gradual and the rate of change of superelevation is decreased.

With increased speed, the superelevation has to be increased, the superelevation being given not for the maximum speed but for the average or weighted average speed (*vide* para 1305).

Increased attention should be paid to the surface of the curve, the difference in levels of the inner and outer rail being kept uniform, as any variation results in the load being increased on one or the other rail.

The gauge should also be corrected, as variation in gauge or an unnecessary wide gauge, results in the vehicles tending to move from side to side, producing lurches and rough running. To prevent the possibilities of spread of gauge, rail braces (*vide* para 1109), may be fixed at intervals along the curve.

With increased speed, greater attention to the spacing and renewals of sleepers on curves is necessary. Rails also wear more rapidly and need earlier renewal. To decrease rail wear, rail lubricators (*vide* para 214), may be introduced.

If sharp curves exist in the track, it is advantageous to eliminate them by introducing flatter curves on a new formation. This is an expensive item, but is often well worth the expenditure, particularly if it avoids a permanent speed restriction.

1517. Regrading of sections

Alterations in grades may be effected for :

(1) Removing steep humps and sags in a track. These may be found in the existing track in hilly country and the anticipated heavier loads may tax the capacity of the engine or adversely affect the speed.

(2) Introducing flatter grades at starting points. The existing grade may be reasonable for the existing load but may be difficult to negotiate with heavier loads, without unnecessarily increasing the capacity of the engines.

(3) Eliminating steep grades in hilly country to enable heavier loads to be hauled at increased speed. This may involve very heavy work, including sometimes the construction of tunnels and spirals. Such work may result in an increase in the length of the track over the existing length. An alternative is to use more powerful engines or more than one engine per train, but this is

uneconomical in the long run, due to the time lost in attaching and detaching the extra engines and the cost of maintaining extra engines.

1518. Improved drainage and stability of formation

An improperly drained track cannot be maintained in the excellent condition necessary for high speed and heavy traffic, since soft formation cannot carry heavy loads and the track does not possess the necessary lateral strength. Particular attention has therefore to be paid to adequate drainage, particularly in cuttings and on formations of poor soil. If due to soft and friable nature of soil in slopes of cuttings, the side drains silt up rapidly, masonry drains may be introduced. These are easier to clean and maintain. The cutting slopes may be turfed so that the soil may not be easily eroded. Alternatively the slopes may be pitched for the full height or along the lower portion of the slope. Sometimes bullies or poles are driven in the formation on either side of the track to support it on very poor formation.

If the soil under the track is waterlogged, perforated pipes may be used with advantage.

When the formation under a track consists of poor soil, consisting of clay and particularly black cotton soil, the maintenance of the track becomes difficult because of the possible failure of the formation. The failure may be a drainage failure or structural failure.

Drainage failure may occur as clay soil is impervious and may become slushy in rain if not well drained. The slush fills the ballast voids, resulting in the track losing its resiliency as well as its line and level. The position is aggravated with black cotton soil which swells with moisture and cracks heavily when dry.

Structural failure occurs due to reduction in the shear strength of poor soil when wet, resulting in heaving of cess.

Many remedies are adopted to improve such formation, depending on the condition of the track and the magnitude of the defect.

One of the principal requirements is to improve the drainage and this applies particularly to side drains in cuttings. In case of banks, drains about 4′ deep may be cut across the track at intervals and filled with ballast lined with sand.

If the ballast is fouled, screening and reballasting are necessary.

For strengthening the formation, pressure grouting, in which a mixture of cement and water are injected into the formation,

through steel tubes driven at short intervals, has been used in America. Hydraulic grouting by "mudjacking" is also used in that country.

For consolidating poor soil and improving its bearing capacity, sand piling has also been used in the same country. This is done by driving 9″ dia. steel or timber spuds with conical ends into the formation for a depth of about 5′ below the bottom of the sleepers, removing the spuds, and filling the holes with sand. One pile on each side of each rail is provided normally at every fourth sleeper. The soil is consolidated by the driving of the spuds and water is drained in the piles, rises by capillary action and evaporates, resulting in an improved formation. The water that can flow down the sand piles during rainfall is only a fraction of that which flows upward through capillary action.

Spreading sand on top of ballast is yet another expedient which is improved upon by introducing a sand blanket between the formation and the ballast. This has proved successful in India. A satisfactory method is to remove all shoulder ballast and that between the sleepers upto a level of about 3″ below the bottom of the sleepers, unloading sand and lifting the track if possible by about 3″ which results in a 6″ layer of sand. Ballast is then unloaded and packed, followed by unloading of further ballast, if necessary, and further packing. Excellent results have been reported with this method on bad stretches of track.

The most elaborate method of formation improvement is that used in Britain, of blanketing. This is done by dismantling the track, removing the soil to a depth determined by soil investigations, providing the required thickness of blanket, invariably of sand, and reballasting, relaying and packing. The functions of the blanket are to structurally strengthen the formation, to provide a drainage medium, and to prevent the poor soil from working up and filling the ballast voids.

Consolidation of poor soil through injection of chemicals is likely to be increasingly used in future. For sandy soils containing less than 25 per cent clay and silt, injection of silicate of soda followed by calcium chloride is effective. Other chemicals such as Krilium are also used.

1519. Strengthening bridges

In any work of track improvement for heavier loads and higher speeds, the strength of bridges has to be considered. Girders, which are incapable of bearing the heavier loads, may be strengthened by riveting or welding additional plates. The plates may be

added to flanges, if the girder is weak in bending, or to the web, if it is weak in shear. The components of the girder may be welded together if the existing rivets are inadequate. Arch culverts may be strengthened by introducing an additional arch ring over the existing ring or converting the arch culvert to a box culvert or by replacing the arch by a girder of adequate strength. Weak box culverts or flat top culverts may be rebuilt or replaced by reinforced concrete pipes. Details of such work are however beyond the scope of this book.

1520. Summary of requirements for a high speed track

(1) The alignment should be perfect both on straight portions and on curves.

(2) The surface should be perfect, particularly on curves.

(3) The gauge should be uniform and correct.

(4) Minor defects should be located and attended to without delay.

(5) If heavy work, such as surfacing, is done on the track, this should be followed up with spot surfacing, as minor defects are apt to develop after work of this nature is carried out.

(6) The drainage should be adequate.

(7) Anchoring should be sufficient to prevent creep.

(8) Battered rail ends should be repaired in one of the several ways indicated in para 1511.

(9) Worn fishplates should be improved as explained in para 405.

(10) Fishing surfaces of rails and fishplates should be adequately lubricated.

(11) Fishbolts should be properly oiled and tightened.

(12) Spacing of sleepers should be correct.

(13) There should be no irregular variation in superelevation.

(14) The quantity of ballast should be adequate and it should be of good quality.

Emergency Measures and Special Works

1601. Accidents

ACCIDENTS may be due either to errors of judgment of individuals or to forces of nature or to defective materials. All possible steps are taken to reduce accidents due to the human element to negligible proportions by numerous devices such as interlocking, block instruments, etc. The majority of accidents due to errors are of a trivial nature, and occur in yards due to misreading of signals, wrong setting of points, moving beyond the authorised limit, etc. It must be remembered that the word accident is here meant to signify not only injury to persons, but mostly damage to vehicles, tracks, structures, etc. Under accidents caused by forces of nature, may be classed damage caused by floods, storms, cyclones, and on rare occasions, by earthquakes.

Accidents are classified according to their nature and extent. The classification enables those, who have to deal with any aspect of the accident, to obtain a fairly good idea of what action they ought to take. Information is sent over the railway telegraph wires. The control telephone should be used unsparingly to receive or issue instructions, order out material, tools, labour, etc. It is essential that the most accurate information is sent by the first official to reach the spot. Messages should be concise and clear and all irrelevant matter should be avoided.

If the accident entails the temporary detention of a train between stations, adequate precautions must be taken with detonators, lights, etc., to prevent another train from approaching. It is essential for the staff to reach the site of accident with the least possible delay, by any means available. At selected stations, wagons, called *Break-down vans*, are permanently maintained, filled with all possible repair implements, including powerful lights for work at night. *Break-down trains* are on a more elaborate scale and often include a mobile lifting crane, carriages for staff and an ambulance vehicle. These can be taken to the site of accident at very short notice.

Speed, consistent with safety, is the essence of all work pertaining to the removal of any obstructions from the track and repairs to the track. If a wagon happens to be derailed, vehicles on either side should be moved away to give room for work. If the derailed wagon is heavily loaded, it should be emptied. Traversing jacks, which lift heavy loads, as well as move them sideways, are most useful for re-railing vehicles and two such jacks are invariably kept on each engine. Much valuable time can be saved if, before applying the jack, it is properly oiled. Wooden packings should be placed between the axle box and the bottom cross piece of the axle guard, when jacking up the vehicle, otherwise the wheels will not lift readily with the wagon frame.

If the removal of an obstruction is likely to take considerable time, and if the width of formation permits, the track should be diverted past the obstructions. The track could then be opened for traffic before completion of the re-railing work.

Ramps, which consist of shaped plates, are also used for re-railing purposes. The ramps are placed in front of derailed wheels and the vehicle is pulled by an engine. The wheel travels over the sloped surface of the ramp on to the rail. If derailment or damage occurs on a double line, the track with the lesser damage must be repaired first and opened for traffic. When a *mobile crane* is used, it should be brought to the site with the jib facing the derailed vehicle. When lifting a vehicle with the crane, the wire ropes from the jib must be vertical, otherwise lateral displacement of the vehicle will take place and cause more trouble. Before lifting heavy loads, the holding chains fixed to the crane chassis must be attached to the rails to prevent the crane tilting forward. Outriggers should also be used as a precaution against tilting of the crane. When the crane is in use, only one person should give orders, as conflicting instructions from several persons is dangerous. The criterion in all accidents must be to clear the track of obstructions and restore it, in the least possible time, for normal use.

The cause of an accident has to be investigated. All relevant data must, therefore, be collected on the spot and before all evidence is obliterated on account of the repair work. But the collection of such data must, under no circumstances, delay or interfere with the repair work. Time should not be wasted during repair work in prolonged arguments as to the cause of the accident. There will be time enough for that after the repairs are completed. Enquiries are subsequently held jointly by representatives of various departments, to investigate the cause of the accident, if the cause is obscure. The main objects of the enquiry are to establish the cause of the accident and find remedies to prevent repetition. Any attempt at shielding individuals or departments responsible is to be deprecated as this defeats the object of the enquiry.

1602. Washaways and damage caused by storms

Although sufficient waterway, in the form of bridges and culverts, is provided under tracks, the track with its formation and culverts is sometimes damaged due to abnormal floods. Such floods are sometimes aggravated by embankments of large irrigation reservoirs giving way due to an abnormal quantity of water entering the reservoirs. Landslides sometimes block tracks in cuttings. Storms and cyclones also cause a lot of damage and obstructions, such as uprooted trees, have to be removed from the track. Patrols help to give warning of impending danger and prompt action at threatened places is essential, if serious consequences are to be avoided.

When a portion of an embankment is washed away, filling the gap with ashes is the most rapid means of carrying out repairs. The ashes are available in large quantities in loco yards and can be loaded in wagons at several loco yards simultaneously. Whilst the ashes are on the way, the track, which is usually pulled out of position and distorted by floods, is straightened and pulled into position. If the gap is short, the track is raised on *cribs* made of old wooden sleepers to form a sag, sufficiently shallow for wagons to negotiate. The ash wagons are brought carefully on this track and the ashes unloaded. The operation is repeated till the ashes are brought up to sleeper level. The track is then packed and slightly lifted on the ash filling. The process of lifting and packing is continued till the track is raised to the desired level. Ashes not only form a good filling material but are an excellent temporary substitute for ballast. This material can be handled comfortably, even in very wet weather, in which earth would turn into mud. The cribs may be so spaced that they support the ends and centres

of each rail length, namely two cribs per rail length are sufficient for the passage of wagons loaded with ashes. Engines should, under no. circumstances, be brought on a track supported in this manner. If the gap is long, it is advisable to do the filling in such a way that on completion of temporary repairs, a large dip is left in the track, with grades which can be negotiated by trains. This reduces considerably the quantity of material required and, therefore, the time for repairs. The track is brought subsequently to its original level by further filling and lifting, in the intervals between trains. If there is delay in the supply of ashes, wagons filled with earth, excavated from a convenient cutting, are equally useful.

Ashes are easily washed away by flowing water; this does not occur in still water. This material has, therefore, to be protected in flowing water and it is usual to dump rubble in flowing water up to a little above water level and fill ashes on the rubble layer. If rubble is not available in sufficient quantities, ridges of rubble may be made along the toes of the original bank to break the current. Ashes may then be filled between these ridges. Gunny bags, filled with ashes, form a fair substitute for rubble for such protection. An important point to remember is that side dumping from wagons is infinitely quicker than end dumping, as in the former case unloading can proceed from as many wagons as can be accommodated on the breach, and as soon as the wagons are empty, other loaded wagons can be brought to site. In case of end dumping, all the material has to be carried after unloading and this is a very slow process. The unloaded heaps must be cleared by pulling them aside for widening the bank, or the track must be lifted before further dumping is done, as accumulated heaps cause delay. Particular care must be taken to see that the surfaces of the rails are clear of ashes before wagons are moved, if derailments are to be avoided.

If culverts are damaged, but not very seriously, they may be strengthened by installing cribs under them.

If the damage is serious, or if a big bridge is concerned, a diversion of the track is the quickest solution. Repairs or rebuilding of the culvert or bridge is subsequently carried out without hindrance to traffic.

Scours in the sides of banks can be filled with ashes, or rubble, by end dumping if the track has been rendered unsafe, or by making the track sufficiently strong on cribs to permit side dumping. Filling may also be done with earth excavated in the vicinity and carried in baskets.

Scours in banks at corners of wing walls must be prevented at all costs from extending during a flood, if the isolation of the abutment and subsequent damage is to be avoided. All available materials on the spot such as rubble, old sleepers, branches of trees or brushwood, weighted with rubble, should be used to prevent the extension of the scour.

After a flood, soundings should be taken round abutments and piers of culverts, to find out if there are any scours, or if the piers or abutments are partially undermined. Rubble filling is helpful in such cases. Rubble filling, freely grouted with cement mortar, also forms substantial temporary bases for bridge supports.

Materials and equipment which are most useful for repairs to breaches are ashes, rubble, gunny bags with twine, old wooden sleepers, bullies, bottle jacks, power lamps, flares, shovels, powrahs, steel baskets, beaters, ropes, and one or more portable telephones.

In addition to the breakdown vans and trains, it is a sound policy to have a set of wagons, at one or two selected stations, ready loaded with ashes and rubble during the months of heavy rains and storms, so that these may be promptly despatched to a breach at any place.

Wise planning, a very clear idea of the sequence of operations, thorough organisation of labour, and the capacity to foresee the requirements of materials are the secrets of successful and rapid repairs of breaches. When a large number of freshly recruited men are employed, they should be divided into gangs of not more than 20 each, and each gang put in charge of a competent gangman. Instructions should be precise and clear and the area of operation of each gang should be clearly defined. Bunching of men, in one or two spots, must be avoided as this leads to decreased output. Work has often to be done at night, but not more than 50 to 75 per cent of the day's output may be expected during the night shift, due to various difficulties. The men detailed for night work must be separate from day labour and the most experienced and reliable gangs should be selected for night duty. Arrangements should also be made for water and food for the large number of men employed.

1603. Diversions

Diversions are sometimes required in connection with breaches, or for heavy repairs or rebuilding of a bridge.

Before laying a diversion, the following items have to be decided : (1) the distance *d* (Fig. 1603) of the diversion from the

existing track, (2) the degree of curve of the four curves necessary in a diversion, (3) the gradients of the diversion.

The distance d depends on the clearance required from the existing track for the necessary repairs or for avoiding obstructions. The degree of the four curves is usually the maximum degree normally used in practice, e.g., 8° to 10° for broad gauge. Usually the diverted track at G is at a much lower level than the track at H, in order to save earthwork. The level of track at G is governed by the maximum gradients over the diversion.

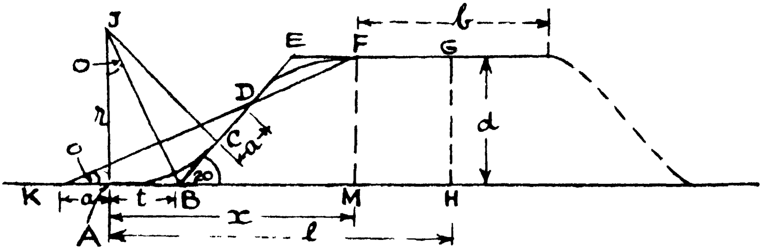


Fig. 1603

The gradients are normally limited to the ruling gradient of the section and compensated for curves. Steeper gradients are sometimes used to overcome difficulties, such as deep cuttings on either side of the bank, along which the diversion is to be laid, or a deep valley. In such cases, trains, negotiating the diversion, are made shorter than the standard lengths, or an additional engine is used with standard length trains. Speed over diversions is usually limited to five miles per hour.

To set out the diversion, the length l and the tangent length t are required. A length b is kept straight and level and a short straight CD is introduced between the curves AC and DF. These straights may in case of shortage of space be omitted.

In Fig. 1603 angle DBM = CJA = 2 BJA.

In triangle KBD, KB is made equal to BD.

Hence angle DKB = KDB and therefore angle DBM = 2 DKB.

Triangle AJB and KFM are similar.

$$\text{Hence } \frac{AB}{JA} = \frac{FM}{KM} \text{ namely } \frac{t}{r} = \frac{d}{KM} = \frac{d}{(x + a)}$$

$$\text{or } t = \frac{d\,r}{(x + a)}$$

$$x = 2t + \sqrt{2(t + a)^2 - d^2}$$

$$(x - 2t)^2 = 2(t + a)^2 - d^2$$

$$\text{hence } x^2 = 4\,t(x + a) + a^2 - d^2$$

$$= \frac{4\,d\,r}{(x + a)}(x + a) + a^2 - d^2$$

$$\text{therefore } x = \sqrt{a^2 + 4\,rd - d^2}$$

$$\text{and } l = x + \frac{b}{2}$$

1604. Repairs to damage caused by enemy action

If a track or bridge is damaged by enemy action, the method of repairs would follow the lines indicated in para 1602. The gaps in the tracks would, as a rule, be shorter than those in case of washaways, but there would possibly be a larger number of such smaller gaps. Bombing is invariably concentrated on important bridges, vital yards, and entrances to tunnels.

The major item of work after an air raid on a railway yard is not so much the filling of bomb craters and repairing the track, but the removal of the tangled mass of steel work and debris of destroyed vehicles and structures. The working of the yard may have to be radically altered temporarily. Signalling and interlocking suffers heavily in an air raid and the speed with which normal traffic is restored in a busy yard, depends partly on the ability to repair the interlocking gear and the signals. Even if the yard is made normal in all other respects, delays caused to trains and shunting operations due to lack of signalling and interlocking devices, is apt to throw the working of the railway completely out of gear.

Buildings in a dangerous condition adjoining the track have to be pulled down.

In case of damaged bridges, special light girders are built up on the approaches and cantilevered out. This, however, is a subject beyond the scope of this book.

The reopening of blocked tunnel entrances depends on how soon the debris can be removed from a restricted area of operation and the damaged tunnel repaired.

Labour is not likely to be easily available, and specially trained units or even troops may have to be used.

Immediately after an air raid or a bombardment, patrols proceed, with the least possible delay, to investigate and report the extent and location of damage, so that prompt action may be taken for repairs. The patrols usually consist of selected dependable track men. Unexploded bombs are a source of danger and are to be handled only by special bomb disposal squads, the members of which are highly trained in such work. As vibration is liable to cause an unexploded bomb to go off, trains are not allowed within a considerable distance of such a bomb.

No hard and fast rules can be laid down for such contingencies. Each incident has to be treated on its merits but difficulties are not insurmountable to men with initiative and courage.

1605. Deep trenches under track

Trenches, sometimes narrow and sometimes fairly wide, have to be made under tracks for laying cables, pipes, sewers, etc. The tracks have to be adequately supported to allow trains to pass and the sides of the trench have to be strengthened, to prevent them from crumbling under the load imposed by passing trains.

For supporting the track, shallow plate girders of adequate strength, or a nest of rails, called *rail clusters*, are used. Timber beams are also sometimes used. As illustrated in Fig. 1605*a*, girders A are supported on cribs B_1, B_2 made of wooden sleepers. These cribs are taken down a depth, which depends on the nature of the soil, the span of girder A and the depth of the excavation.

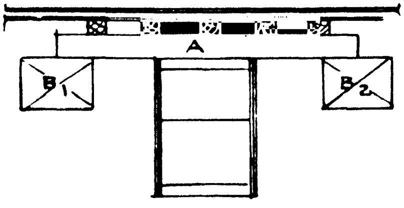


Fig. 1605*a*

After the track has been fully supported on the girder and sleeper cribs, excavation is started and the sides of the trench are strengthened by timbering.

As the free period available between trains for opening the track is limited, particularly as such work is invariably required in or near large towns where the train service is frequent, the work has to be done in stages and mostly at night. High-powered lights are necessary, and it is advantageous to have a large number of smaller lamps than a

small number of larger lamps, as the shadows in the latter case are sometimes troublesome. A large number of lamps also permits greater freedom in their location.

The actual procedure may be as follows : A pair of rails and a few track sleepers are removed, and a pit of sufficient length, breadth and depth is excavated to accommodate crib B_1, the sleeper crib built up to the level of the track sleepers and the track restored after replacing the track sleepers and rails. A similar operation for crib B_2 may be carried out simultaneously, if there is sufficient time and labour

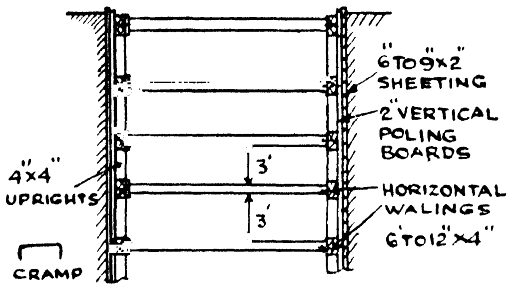


Fig. 1605*b*

available. If not, this operation is carried out when another free period between trains is obtained. During a subsequent free period, the top layers of the cribs are removed and earth is excavated between the cribs, to a depth sufficient to accommodate temporary girders A. The girders are then introduced and the track restored for the passage of trains. It is now possible to excavate the trench, lay the pipe line, or whatever is to be laid or built in the trench, without any hindrance to traffic. The trench is to be timbered and this is done as excavation progresses. After the trench is excavated to a depth of about 3′ to 6′, sheeting boards, 2 inches thick and 6 inches to 9 inches wide, are laid horizontally against the two faces of the trench and strutted (Fig. 1605*b*). For strutting purposes, vertical poling boards and horizontal walings are necessary. The struts are fixed about 4′ to 5′ apart horizontally and about 3′ to 4′ vertically and wedged tight by means of wedges at one end of the strut. Cramps, as shown in Fig. 1605*b*, are fixed between the struts and walings, and between the walings and poling boards, to prevent any of these pieces from falling, if any strut wedges are loosened. Vertical uprights to support the walings are also used. Further excavation is carried out and the operation is repeated. If the earth is compact, the excavation may be completed to full depth without timbering and the timber fixed subsequently. In such cases, the planks are fixed vertically instead of in the horizontal direction and are held in position with walings and struts.

After laying of the pipes, etc. the timber is removed and the trench is filled up. The temporary girders and the sleeper cribs are removed during free periods between trains.

In order to carry out such work successfully, every stage of the work must be properly planned, all necessary materials must be collected at site beforehand, and every detail must be carefully thought out.

1606. Sleeper cribs

These are temporary supports or piers for girders and consist of layers of wooden sleepers, 2 to 5 sleepers being used in each layer (Fig. 1606). They form satisfactory supports and can be constructed in very little time. The base consists of a layer of sleepers, laid close together on ground, made level either by filling or excavating. It is very necessary that all layers should be level and for this purpose thin pieces of timber have sometimes to be driven between the contact surfaces of sleepers in the various layers. These fillers should be of the full width of the sleeper and use of small chips must be avoided. In order to make the crib compact, spikes are sometimes driven through sleepers in each layer. Cramps are also used in place of spikes. When a crib is to be placed in shallow water, the area to be covered by the crib is filled with earth and brought up to a little above the water surface. Such filling is protected against erosion with rubble, or with gunny bags filled with earth.

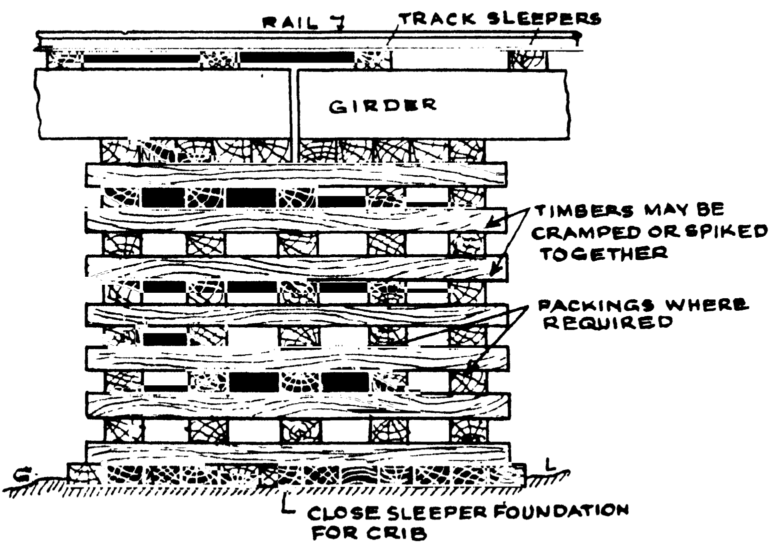


Fig. 1606

A more substantial and lasting foundation, for a crib located in water, is obtained by grouting rubble filling with cement mortar. This filling is also brought to a level a little above the water surface and the crib is then built over this.

When high cribs are required, in connection with repairs of high bridges, in order to obtain a more stable crib, double cribs are used for a part of the height, and single cribs constructed for the remaining portion. To prevent possibilities of unequal settlement, old rails are threaded through the double cribs at intervals.

Although trains are passed over cribs at not more than walking speed, the layers of sleepers are liable to get loose. The packings between the sleepers have therefore to be constantly tightened. If old sleepers are used in the crib, this packing has to be done at even shorter intervals. Half inch to three-quarter inch diameter vertical rods at the four corners of the crib, threaded through holes in pieces of rails, fixed below the bottom and above the top layer of the crib, make the crib fairly compact. The nuts at the top of the four rods enable any slack in the crib to be taken up. For greater stability, the cribs may be filled with rubble, and rubble may also be placed outside the base. The cribs should be built an inch or two higher than the required level to allow for compression and settlement under load.

1607. Framed trestles and piled trestles

Framed trestles are far more economical in material than cribs, and consist of a number of vertical posts or uprights fixed on a timber ground sill (Fig. 1607). The sill is laid on a layer of closely placed sleepers. A cap sill is fixed on top of the posts and the girders rest on top of the cap sill and at right angles to it. Rakers at a slope of about 6 to 1, are sometimes fixed on either side of the frame for lateral stability. The ground sill must be centrally located on the layer of bearing sleepers for even pressure on the ground. The tops of the uprights have also to be in one level, so that the load from the girder is evenly distributed on them through the cap sill. Two cross bracings, each with a cross section about half that of the uprights, are provided and all junctions are well bolted. The uprights may be held to the ground sill and cap sill with suitable straps screwed to the timbers, or with cleats of angle iron, or with cramps. Each support may consist of a single frame or two frames braced together. The double frame is desirable for greater stability and better load distribution on ground. Reliable timber such as teak, of good quality and of substantial width and thickness, is required for framed trestles. As timber of suitable

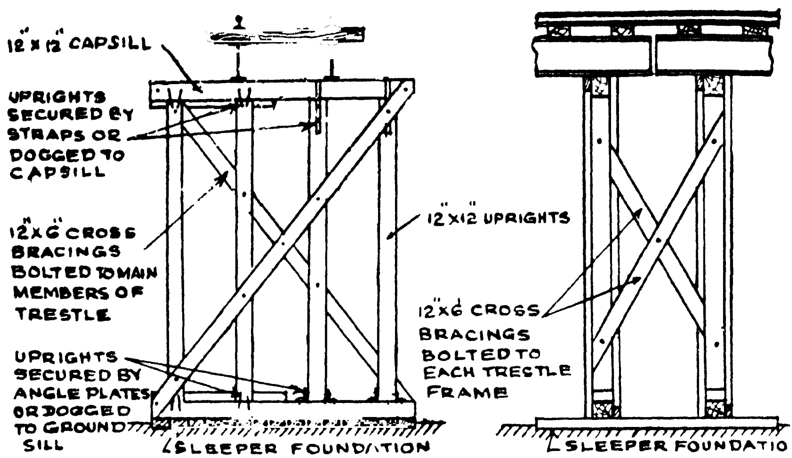


Fig 1607

size for trestles is not easily available in emergencies, as the load distribution on the ground is not as good as with cribs, as cribs do not require as much skill in construction as trestles, and as cribs are less liable to displacement by horizontal forces than trestles, sleeper cribs are generally used in emergencies.

When temporary supports are required to be built in water or on soft ground liable to floods, piled trestles are used The uprights, or piles, are driven into the ground and braced together as in framed trestles Cap sills, braces and rakers are used, but there is no ground sill This is replaced by a waling, just above water level A single frame is usually sufficient.

1608. Service girders and rail clusters

Girders, for temporarily supporting the track, may consist of timber baulks, rolled steel joists, built up plate girders or clusters of rails As vertical clearances are usually restricted, a pair of joists under each rail is preferable to a single joist or a built-up girder of greater depth (Fig. 1608*a*) The joists are supported, at the ends, on a layer of sleepers or on sleeper cribs, and held to these with spikes. The joists are also held in position horizontally with rods or flat irons. If, due to a very restricted vertical clearance, it is not possible to raise the track or lower the support, composite girders as shown in the lower illustration of Fig. 1608*a* are used. In an emergency, when it is not possible to

obtain suitable joists, rail clusters, which consist of nests of rails suitably held together, as shown in Fig. 1608*b*, are used. The rails

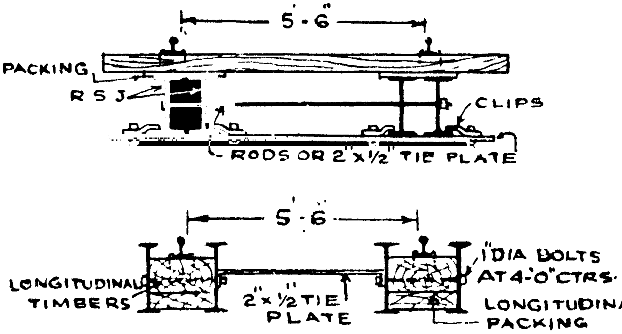


Fig. 1608*a*

in the clusters are held together with angle irons, or fishplates, and suitable bolts as shown in Fig. 1608*c*. In case of inadequate

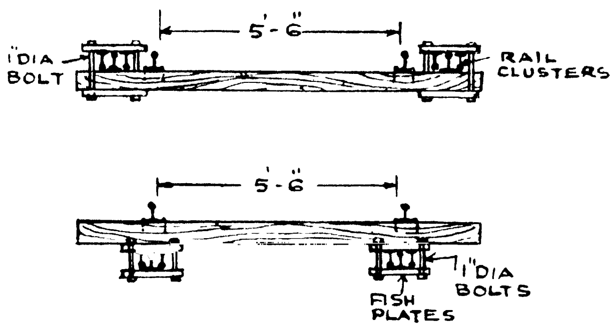


Fig. 1608*b*

clearance, the track may be suspended from rail clusters as shown in the top illustration of Fig. 1608*b*. Rail clusters are very handy

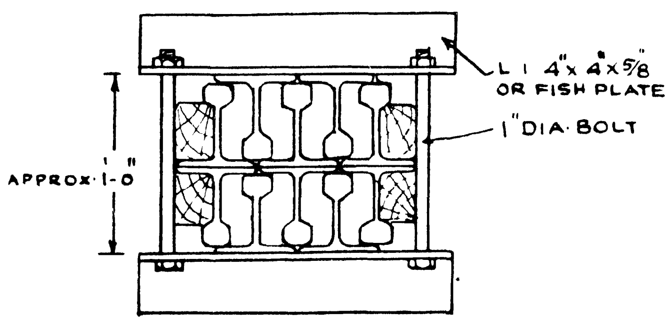


Fig. 1608*c*

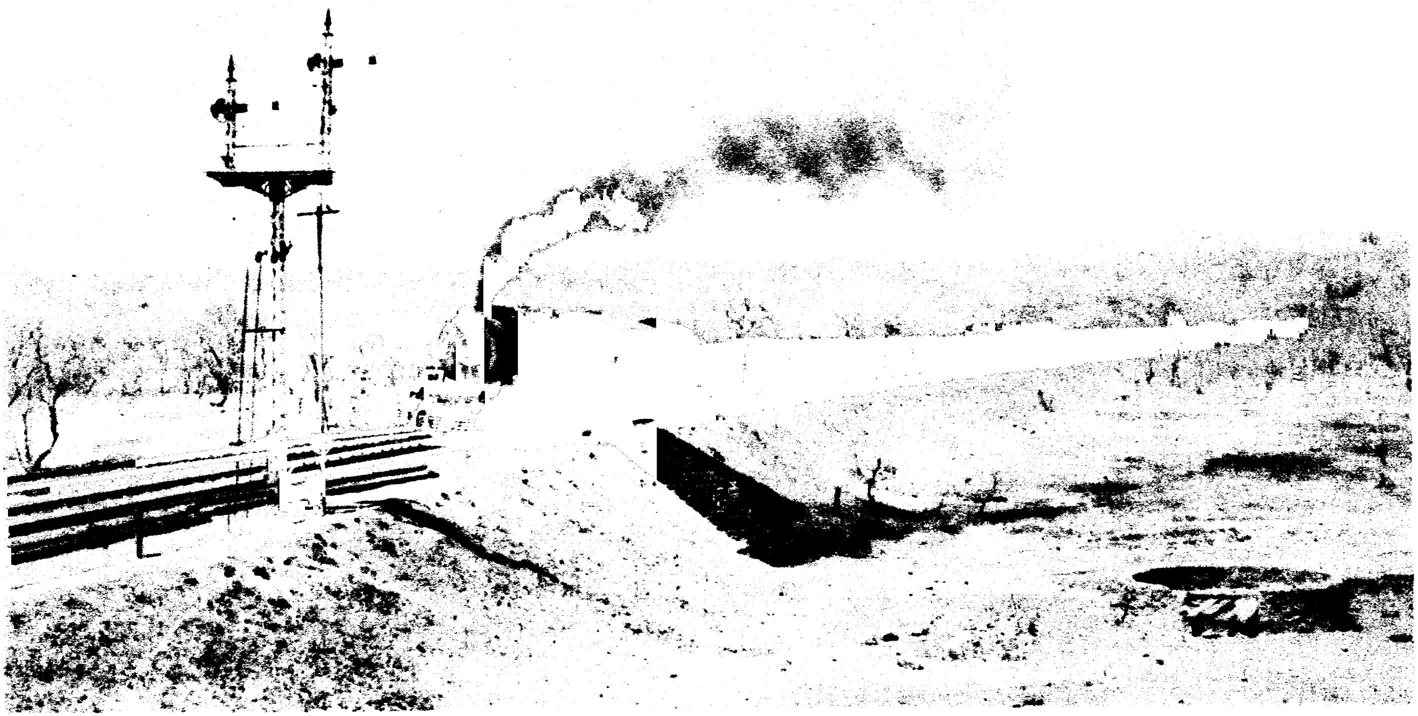
in emergencies as rails, fishplates and bolts are readily available. The number of rails to be used in each cluster for various broad gauge spans are as follows :—

Span	5′ to 7′	8′	9′ to 10′	11′ to 12′	13′ to 15′
Number of rails in each cluster with 90-lb. rails.	3	5	5	7	10
Number of rails in each cluster with 75-lb. rails.	5	5	7	10	Not to be used.

For a cluster of 10 rails, a double layer, with 5 rails in each layer should be used as shown in Fig. 1608*c*. These numbers have been obtained on the following basis. M. L. (main line) loading, namely 22½ tons axle load, has been taken, no impact allowance has been considered and the stress permissible in the rails has been taken as 10 tons per square inch. The clusters must have a firm bearing, of at least 1′-9″, at each end. Trains may be passed over rail clusters at a speed of not more than five miles per hour.

PART 4

Fundamentals of Track Performance



A goods train negotiating a heavy gradient

Track-Vehicle Reaction

1701. General

CONSIDERABLE research has been carried out in India and in other countries on the stresses which a railway track has to withstand with the movement of heavy loads at high speeds over it and to distribute the load satisfactorily to the formation under it.

Upto 1922 the stresses in a railway track were determined on the assumption that the rails formed a series of girders supported rigidly by the sleepers. This assumption was found to be inadequate and since 1922 the elastic theory has been used for calculating stresses. Results of extensive tests in India and elsewhere have proved this to be a satisfactory theory. The assumption in this theory is that the rails forming continuous girders are carried on sleepers which are considered as elastic and not rigid supports. The ballast and the formation as well are considered to be elastic as they regain their former position after being compressed by the wheel loads.

The variables in determining track stresses are so numerous that no precise results can be achieved, but a close assessment through calculations not only forms a basis for correlating results

of tests but also provides a reliable estimate of stresses likely to be produced in a track with different types of vehicles. Such estimates are desirable when new types of locomotives or vehicles are to be introduced or the track is to be improved for higher speeds and loads or a design for a new length of track is to be determined.

1702. Elastic theory of track

The fundamental basis of the elastic theory of track is that the track support is elastic and that the depression of a sleeper is proportional to the load on the sleeper and the recovery is complete after the load is removed. This is not strictly true in practice as due to displacement of ballast or formation or due to crushing of the ballast, the recovery is not complete. This aspect however is not accounted for in theoretical considerations, and any depression in the track is supposed to be set right with the least possible delay.

Assuming that the wheels are uniformly loaded, the path of the wheels will be horizontal and the track will be depressed on the approach of the wheel and recover after the wheel has passed.

If the track is considered as a uniformly loaded structure supported on wheels (this can be visualised by imagining the track and the load turned upside down), the track will bend between the supports, namely between the wheels (*vide* Fig. 1702*a*).

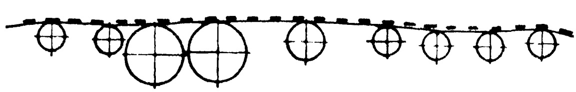


Fig. 1702*a*

Due to continuity, the track forms a sinusoidal curve.

The effect, both in flexure or bending and in deflection or depression, due to a single wheel load extends over a certain length of the track, and is depicted in Fig. 1702*b*. It will be noted that at a certain distance from the wheel load the bending moment becomes negative. If another wheel-load is situated within this distance the bending moment produced by it is reduced by the amount of negative bending moment caused by the wheel load.

The track depression curve in Fig. 1702*b* shows that upto a distance of 120″ the effect on track depression is additive.

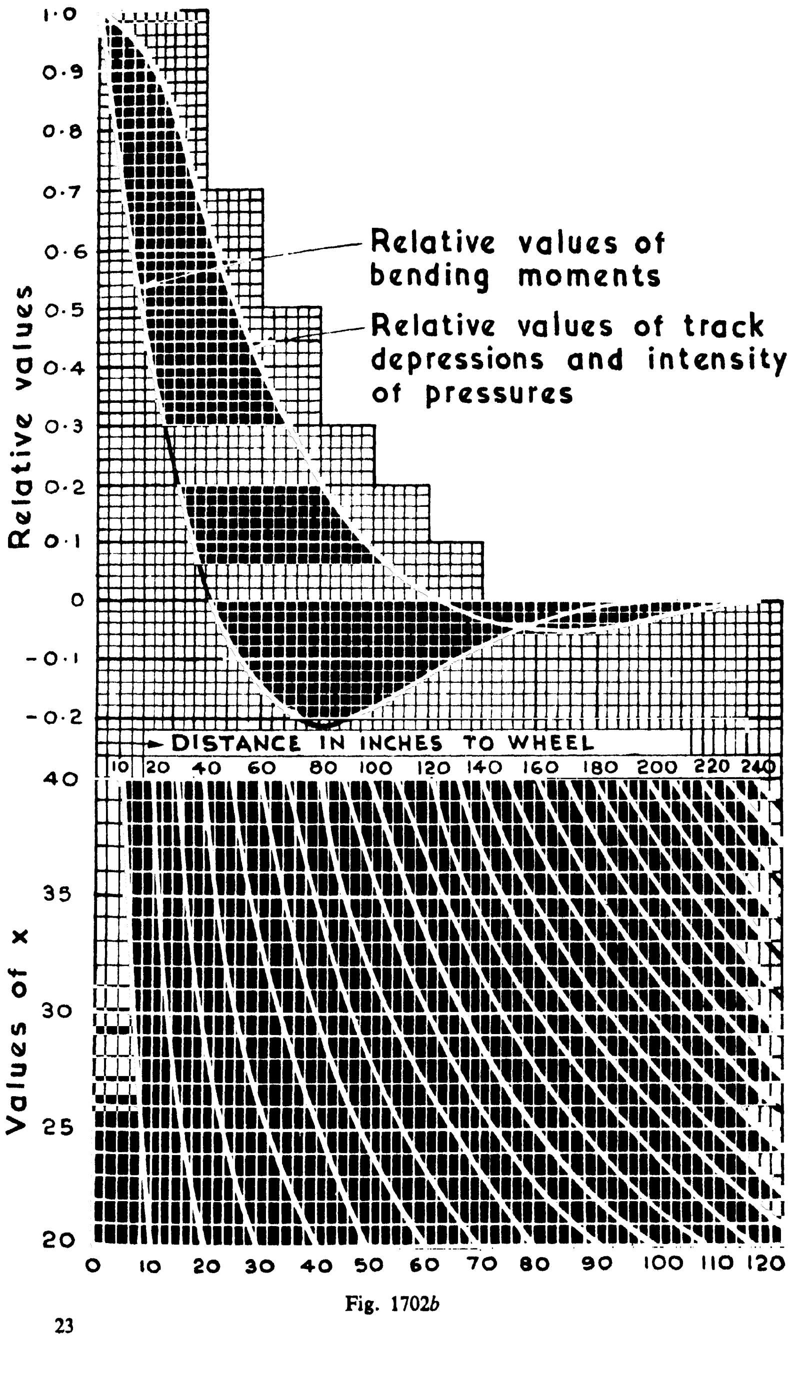

Relative values
Values of x
Relative values of bending moments
Relative values of track depressions and intensity of pressures
DISTANCE IN INCHES TO WHEEL
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
-0·1
-0·2
10 20 40 60 80 100 120 140 160 180 200 220 240
40
35
30
25
20
0 10 20 30 40 50 60 70 80 90 100 110 120

Fig. 1702*b*

In other words, the effect of an adjoining wheel is to reduce the bending moment but to increase track depression.

1703. Track modulus

The rigidity of the track support is termed the elastic modulus of track or track modulus.

Track modulus is the weight in pounds per inch length of rail required to produce a deformation or depression of 1 inch in the track.

Modulus of track μ varies with the gauge, the type and spacing of sleepers, nature of ballast etc. It can, however, be easily obtained by measuring the deflection of each sleeper under the rail loaded with an engine of known weight. As stress is the product of modulus and strain, the load per sleeper equals

modulus $\mu \times$ deflection $d \times$ sleepers spacing (i.e. $\mu\ ds$).

Hence half the engine load equals the sum of $\mu\ ds$ over the number of sleepers covered by the engine. From this equation track modulus $\mu\ ds$ is obtained.

The value of track modulus may vary from 400 to over 2,000. On a basis of weights of rails the values may be taken roughly as follows :—

45 to 55 lbs. per yard	700
60 to 80 ,, ,, ,, ...	1,000
80 to 115 ,, ,, ,, ...	1,600
Over 115 ,, ,, ,, ...	2,000

In the absence of actual values of track modulus for particular track lengths, the following approximate moduli may be taken for purposes of calculations.

Broad gauge	1,000 to 1,200
Metre gauge	600 to 700
Narrow gauge	400

1704. Track stress equations

The fundamental equation corresponding with the elastic theory of track is

$$EI\frac{d^4y}{dx^4} + \mu y = 0$$

from which the following equations are derived for values under a concentrated load.

The equation for bending moment M_p under wheel load P is

$$M_p = P \sqrt[4]{\frac{EI}{64\mu}}$$

which reduces to

$$M_p = \cdot 318\ Px$$

where E = modulus of elasticity of rail = 30×10^6

I = moment of inertia of rail

μ = track modulus.

The distance x from load P to point of zero bending moment is

$$x = 82 \sqrt[4]{\frac{I}{\mu}}$$

Track depression y_p under wheel load P is

$$y_p = \frac{P}{\sqrt[4]{64\ EI\ \mu^3}}.$$

which reduces to

$$y_p = \frac{.39P}{\mu\ x}$$

The maximum load on a sleeper under one rail, i.e., the rail seat load is the product of the track depression y, the track modulus μ and the sleeper spacing S, i.e., $y\mu.s$.

The maximum rail seat load P_r with the wheel load P just over the sleeper is

$$P_r = \frac{\cdot 39\ PS}{x}$$

In order to determine the bending moment, the depression and the rail seat load, the values of these for each wheel load, as indicated above, are to be combined. For rapid results, use is made of Fig. 1702*b* for such a combination. Fig. 1702*b* illustrates the bending moments and depressions caused by a single wheel load at various distances from it. The depression curve is required to determine the rail seat load for ascertaining the sleeper strength and the depth of ballast. Instead of determining the bending moment and depressions caused by each wheel load and using Fig. 1702*b* for modifications necessitated due to the effect of adjoining wheel loads, it is simpler and equally correct to carry out the modifications on the wheel loads and work out the bending moments and depressions subsequently.

The effect of the adjoining wheel load depends on the wheel spacing and on x, the distance from the wheel load to the point of zero bending moment.

For example, assuming that the distance from a driving wheel to the adjacent wheel is 65″ and x, as obtained from the formula given above, is 32″, enter the chart at 65″ on "Distance in inches to wheel" and follow the x curve upto a reading of 32″, then along the vertical line from it

(1) to the bending moment curve obtaining a value of $-\cdot 22$ and

(2) to the track depression or intensity of pressure curve obtaining a value of $+\cdot 12$.

A reduction of ($\cdot 22 \times$driving wheel load) is obtained in the adjacent wheel load due to the effect of the driving wheel load. The bending moment is correspondingly diminished.

Again, due to the effect of the driving wheel, the depression or intensity of pressure is increased by ($\cdot 12 \times$ driving wheel load)

1705. Virtual wheel load

The actual load per wheel or the static wheel load has to be modified to allow for the following factors known as *dynamic effects*. A further modification has subsequently to be made for the effect of adjoining wheel loads (as explained in para 1704). The net wheel loads obtained after modifications are known as virtual wheel loads and the bending moments, depressions and intensities of pressure are obtained from these virtual wheel loads.

The dynamic effects which increase the loads on the wheels are caused by

(1) *speed effect*,

(2) *overbalance* or *hammer blow* on the driving wheels,

(3) *steam effect* on the driving wheels,

(4) *inertia of the reciprocating parts* of the engine. The effect of item (4) when phased with the maximum hammer blow is so small that it is often omitted.

In case of diesel and electric locomotives, *torque reactions* of motor-driven axles have to be added whilst the steam effect is eliminated. Torque reaction is maximum at the time of starting and diminishes with speed.

1706. Speed effect

A certain factor has to be added on account of speed to the bending moments obtained for static loads. This factor takes account of several effects including vertical impact due to speed, rail vibrations, effects of rail joints and track irregularities, eccentricity in rail loading, torsion and lateral bending of rail.

The factor is different for the bending moment and for the depression which influences the design of sleeper and depth of ballast. In case of the bending moment, the effects of both vertical loads and horizontal thrusts are allowed for, whereas in the case of depressions, only the vertical loads have to be considered.

Because of the numerous variables involved, these factors cannot be calculated with any degree of accuracy, and are therefore based on results of extensive tests.

The formula for factor k_b for bending moment is based on Indian research and is

$$k_b = \frac{v}{3\sqrt{\mu}}$$

where v is the speed in m.p.h. and μ is the track modulus.

The factor k_t for depressions obtained from German experiments is

$$k_t = \frac{v^2}{12000}$$

1707. Effect of curvature of track

The rail on a curve is subjected to stresses due to two causes in addition to the stresses in the rail on the straight track. These causes are (1) lateral bending of the rail due to the rigid wheel base of vehicles. This lateral bending is considerably reduced when bogies are used. (2) An extra vertical load on the inner or outer rail depending on the amount of superelevation and the speed of the vehicle.

The additional vertical load at slow speed due to curvature is taken as (3 × superelevation) per cent for broad gauge and (5.5 × superelevation) per cent for metre gauge.

1708. Hammer blow and effect of reciprocating masses

The driving wheels of a locomotive are the wheels which are revolved by the energy imparted to them by the power unit.

Some of the connecting parts such as the crank pin and connecting rod between the power unit and the wheel and also coupling rods forming a connection between the driving wheels (Fig. 1708) revolve with the wheels and develop centrifugal forces. Such

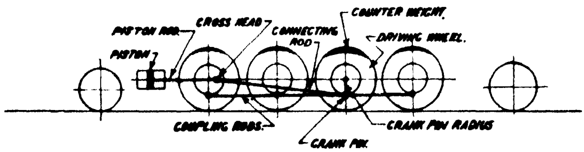


Fig. 1708

eccentric revolving masses have to be balanced and this is done by introducing counterweights near the rim of the wheels on the side opposite to the *revolving masses*.

With steam locomotives, the *reciprocating masses* such as the piston, piston rod, and part of the connecting rod set up side oscillations and nosing due to inertia induced by their forward and backward movement. *Nosing* is a tendency of the front wheels to impinge on the rails at an angle in the forward direction. The oscillation of a locomotive has been aptly compared with the movements of the legs of a running person, the weight introduced in the wheel to counter oscillation being comparable with the moving arms of the runner. This tendency towards side oscillation and nosing has to be checked and this is done by introducing counterweights on the side opposite to the crank pin and combined with the counterweight for the revolving masses (Fig. 1708). Due to various reasons the reciprocating parts cannot be fully balanced, and only a percentage is balanced.

As the counterweight revolves with the wheel, its horizontal and vertical components vary. The horizontal component is beneficial and counteracts the oscillation but the effect of the vertical component is harmful. In each revolution, it produces an impact or a vertical blow known as *hammer blow* on the rail and also an upward lift. The effects of the hammer blow have to be taken into consideration not only in assessing the strength of rail and the track but also of structures such as bridges. The effect increases with an increase in speed. That portion of the counter-weight which is not required for balancing the revolving masses is known as *over-balance*. *Percentage over-balance*, a term frequently used, is therefore that percentage of the reciprocating masses for

which counterweights are provided to reduce oscillations but which induces a hammer blow on the track. It will be obvious that an increase in the percentage of over-balance improves the riding qualities of the locomotive as the lateral thrust exerted by the wheels of the rails is reduced but increases the vertical load (hammer blow) on the track and structures over which the locomotive runs.

Sometimes it is not possible to introduce counterweights sufficient even for balancing the revolving masses and the locomotive is said to be *under-balanced.* The adverse effect on track and structures of an under-balanced locomotive is greater than that of an over-balanced locomotive.

As there are no reciprocating masses in electric and diesel electric locomotives, the hammer blow is caused by revolving masses only.

The percentage over-balance or *out-of-balance* of the counterweight on any wheel is given as the weight in pounds at the crank radius. The value varies with each type of engine and the range may extend to nearly 70 per cent over-balance.

The hammer blow is the centrifugal force of the over-balance or the unbalanced weight and is obtained from the equation of the centrifugal force,

$$\text{i.e., } \frac{mv^2}{g}$$

$$\text{The value works out to } .0015\ \frac{wv^2r}{d^2}$$

where w is the over-balance in pounds, v is the speed in m.p.h., r is the crank radius in inches, and d is the driving wheel diameter in inches.

1709. Steam effect

The energy due to the pressure on the engine piston is translated to the driving wheel through the connecting rod. The connecting rod being at an angle to the horizontal except at the beginning and at the end of the strokes, has a vertical component which acts at the crank pin and creates further hammer blows, the magnitude of which varies with the angle of

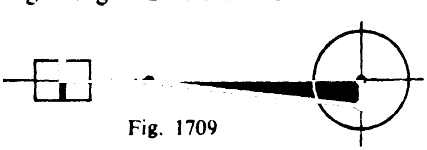


Fig. 1709

the connecting rod. The maximum hammer blows due to steam pressure on the pistons occur at mid stroke of the piston (*vide* Fig. 1709). These maximum valıes do not however coincide with the maximum hammer blows due to overbalance. The magnitude of the steam effect which is to be added to the hammer blow effect is the vertical component with the connection rod in a position coinciding with the vertical position of the balance weights on the wheel. The value is obtained by (1) multiplying the piston area by the net steam pressure as obtained from indicator diagrams, with the piston in a position corresponding with the vertical position of the counterbalance, (2) obtaining the component of this steam pressure in the direction of the connecting rod, and (3) obtaining the vertical component of (2) and multiplying this by a mechanical efficiency factor of 0.8.

The magnitude of the steam effect is small when compared with the value of the static load plus speed effect.

Track Stresses

1801. Bending moment and longitudinal stress in rails

THE stresses which a rail has to bear are those due to

(1) Loads on wheels and the effect of adjacent wheels

(2) Effect of speed which cover several factors such as track irregularities

(3) Hammer blow

(4) Horizontal thrust due to the nosing action of a locomotive

(5) Thrust exerted by wheel flanges on sides of rails, increased considerably on curves due to centrifugal forces

(6) Steam effect for steam locomotives and torque reaction for diesel and electric locomotives

The bending moment is obtained from the formula in para 1704

$$M_p = .318\ Px$$

the value of P the virtual wheel load is obtained as explained in para 1705 and the formula for x as given in para 1704 is

$$x = 82\sqrt[4]{\frac{I}{\mu}}$$

The longitudinal stress f in a rail is obtained from

$$f = \frac{Mp}{z}$$

where z = modulus of section of rail.

In case of the leading wheel in a locomotive, and the leading wheel of a trailing bogie, when the bogies of a wagon are placed far apart, the rail stress computed as above should be increased by 10 per cent. This is to allow for the lifting of the rails in front of these wheels due to the vertical bend formed in the rail and the rail supports not developing negative reactions particularly because of looseness in rail fittings.

It may be noted that in working out longitudinal rail stresses under wagons, only the first, second and fifth items, listed above, have to be considered. The ultimate strength of rail steel is about 52 t.s.i. and its yield strength may be taken as about 27 t.s.i. The rail is subjected to reversal of stresses, the magnitude of the reverse stress being less than half the maximum stress. In view of this the fatigue limit of the steel has to be considered. The fatigue limit of steel is normally 45 per cent. of its ultimate strength, hence it may be taken as 23 t.s.i. Based on this the permissible maximum stress has been fixed at 15 t.s.i. which leaves sufficient margin for reversal of stress.

Apart from the longitudinal stresses caused by the vertical wheel load, the rail is also subjected to lateral stresses because of (1) the torque caused by the wheel load being applied not centrally over the rail head but eccentrically and also by the lateral load and (2) the lateral deflection of the rail. This increases the total stress in the rail. As the lateral thrust at any one section of a rail does not occur throughout the passage of a train but occasionally, except on curves, it has been suggested that the limit of stress may be increased to account for this occasional additional stress. The criterion suggested is that the sum of the maximum reversing stress and the occasional lateral stress should be well within the yield stress, say a little over two-thirds of yield stress or 19 t.s.i.

1802. Example

The following examples illustrate the method by which (1) the average longitudinal rail stress under any locomotive is obtained and (2) the permissible speed on an existing track with specific vehicles is ascertained.

(1) *Determination of longitudinal rail stress induced in a 50-lb. rail by a metre gauge passenger locomotive of YP class with* $33\frac{1}{3}$ *per cent. over-balance running at 55 m.p.h.*

The spacings of axles and the static axle loads for a YP locomotive are given in the first and second lines of Table 1802*a*. The speed effect as per para 1706 is

$$\frac{v}{3\sqrt{\mu}} = \frac{55}{3\sqrt{600}} = \cdot 75$$

and the values are given in the third line of Table 1802*a*. Hammer blow effect on the driving wheels, obtained as indicated in para 1708, and steam effect in accordance with para 1709, are entered in the fourth and fifth lines respectively and the total is given in the sixth line.

The distance from the load to the point of zero bending moment

$$x = 82 \sqrt[4]{\frac{I}{\mu}}.$$

$$= 82 \sqrt[4]{\frac{11.44}{600}} = 30.3''.$$

The distance of the second wheel from the first wheel is 75″ and $x = 30.3''$. From Fig. 1702*b* the relief factor $= 0.19$. Hence the relief afforded to wheel load 2 by wheel load 1 $= 0.19 \times 6.83 = 1.29$. The relief afforded by wheel 1 to wheel 3 which is at a distance of 136″ from wheel 1 is $0.01 \times 6.83 = 0.07$. The relief afforded by wheel 2 is given in line 2 of Table 1802*b*. The values are totalled to give the virtual loads. The maximum virtual load being 7.05 tons, the longitudinal rail stress is found for this load.

$$M_p = .318\ Px$$

$$= .318 \times 7.05 \times 30.3 = 68.35 \text{ in tons.}$$

$$\text{Longitudinal rail stress} = \frac{M_p}{z} = \frac{68.35}{5.43} = 12.4 \text{ t.s.i.}$$

which is well below the permissible stress.

TABLE 1802*a*

Wheel No.	1	2	3	4	5	6	7	8	9	10
Spacing ..	75″	61″		60″	60″		98″	109″		60″
Static load ..	3.9	3.9	5.25	5.25	5.25	4.975	4.875	4.875	4.875	4.875
Speed factor ..	2.93	2.93	3.94	3.94	3.94	3.731	3.656	3.656	3.656	3.656
$33\frac{1}{3}\%$ hammer blow			1.37	1.37	1.37					
Steam effect ..				2.32						
Total ..	6.83	6.83	10.56	10.792	10.56	8.706	8.531	8.531	8.531	8.531

TABLE 1802*b*

	1	2	3	4	5	6	7	8	9	10
1	6.83	−1.29	−0.07							
2	−1.29	6.83	−1.4	−0.27						
3	−0.11	−2.16	10.56	−2.22	−0.42					
4		−0.43	−2.27	10.792	−2.27					
5			−0.42	−2.22	10.56	−1.06				
6					−0.87	8.71	−0.61			
7						−0.60	8.53	1.79		
8							−1.79	8.53	−1.79	−0.33
9							−0.33	−1.79	8.53	−1.79
10									−1.79	8.53
Total			6.40	6.082	7.00	7.05				

(2) *Determination of the speed at which wagons with* 12-*ton axle loads may be permitted to run on track with worn* 50-*lb. rails, I and z of the worn rail being* 9.31 *in.*^{4} *and* 4.44 *in.*^{3} *respectively and actual track modulus being* 780.

$$\text{Distance } x = 82\sqrt[4]{\frac{1}{\mu}} = 82\sqrt[4]{\frac{9.31}{780}} = 27.1''$$

$$\text{Static } M_p = .318\,Px = .318 \times 6 \times 27.1$$

$$= 51.8 \text{ in tons}$$

as the static wheel load is 6 tons.

Longitudinal rail stress due to static load

$$= \frac{M_p}{z} = \frac{51.8}{4.44} = 11.68 \text{ t.s.i.}$$

Permissible stress with speed effect should not exceed 15 t.s.i.

$$\text{hence } 15 = 11.68\left(1 + \frac{v}{3\sqrt{780}}\right)$$

$$\text{hence } v = 24 \text{ m.p.h.}$$

1803. Sleeper strength

In para 1704, the maximum rail seat load on a sleeper based on track depression is given as.

$$P_t = \frac{.39Ps}{x}$$

The wheel load P is to be substituted by the virtual wheel load as explained in para 1705.

The speed factor in case of sleepers and ballast calculations, which are governed by track depressions, is given in para 1706 as

$$K_t = \frac{v^2}{12000}$$

The portion of the sleeper which is effective in transferring the rail seat load to the ballast is the area lb (Fig. 1804) where b is the width of the sleeper. The value of l is obtained from a consideration of the thickness t of the sleeper, the overhang or cantilever portion c of the sleeper beyond the rail, and the pressure exerted on the bottom surface of the sleeper by the ballast.

This bottom pressure is not uniform throughout the sleeper because of the flexibility of the sleeper, and the varying pressure can be represented by curves with the maximum ordinate immediately under the centre of each rail. The equation for l based on the above considerations is

$$l = 2c\left(1 - \frac{\cdot 036c}{4\sqrt{t^3}}\right)$$

The strength of the sleepers may be determined from the bending moment M_O of the overhang portion which is

$$M_o = \frac{Pt}{bt} \times \frac{C^2}{2}$$

where $\frac{P_t}{b_t}$ is the uniformly distributed rail seat load.

The stress f_t in the sleeper is obtained from

$$f_t = \frac{M_o}{Z_t}$$

where Z_t is the section modulus of the sleeper.

1804. Determination of ballast depth

As one of the main functions of the ballast is to distribute the concentrated load on the rail and transfer it to the formation, the determination of its depth is an important consideration. The area A of the ballast taken as effective for distributing the load may be considered as the bottom of a pyramid (*vide* Fig. 1804) with a value $= \cdot 5\ bld$ where d is the depth of the ballast.

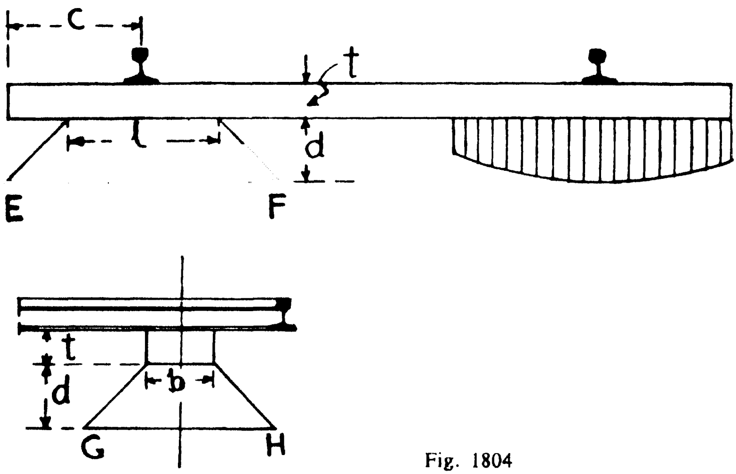


Fig. 1804

The average pressure P_b at formation level is then obtained by dividing the rail seat load by the area A, i.e.,

$$P_b = \frac{P_t}{A} = \frac{\cdot 39\ P_s}{\cdot 5\ bldx}$$

$$= \frac{\cdot 195\ P_s}{bldx}.$$

The computed depth d_c of the ballast is therefore

$$d_c = \frac{\cdot 195\ P_s}{blx\ P_b}$$

American experiments have indicated that because of lack of rigidity in a track structure, play between the rail and sleeper etc., the rail seat load is found to be much higher than the value obtained in para 1704 and that this increase may be accounted for by increasing the rail seat load by two-thirds.

The required ballast depth d may therefore be obtained from the computed depth as follows:

$$d = 1.2/3\, d_c$$
$$= \frac{.325\ P_s}{blx\ P_b}$$

P_b must not exceed the permissible bearing pressure of the soil which makes up the formation. This obviously varies with the type of soil and for great accuracy may need to be determined by soil mechanics. The following figures may, however, be taken as approximate: permissible soil pressure in

(1) uncompacted formation: 20 p.s.i.

(2) compacted formation: 40 p.s.i. and above.

1805. Determination of ballast depth for new loadings

If a certain depth of ballast in a track has been found adequate for the vehicles travelling over the track, it is easy to ascertain whether the same depth would suffice or additional depth of ballast would be required with other vehicles.

American experiments have indicated that the following relationship can be expressed between the depth d of ballast and the maximum pressure P_m below the rail seat centre

$$d = \frac{10\,P_t}{P_m}$$

where P_t is the rail seat load.

For comparison purposes, P_m may be found from the above formula for the P_t of the locomotive or vehicle currently travelling on the track and the existing ballast depth. The same formula may then be applied to determine the required depth with P_t of the new locomotive or vehicle, using P_m as already determined.

1806. Sleeper spacing at rail joints

For satisfactory conditions, the pressure P_t at formation level should be uniform throughout the length of the track. A weakness is introduced at rail joints because of the stiffness of the fishplates not being the same as that of the rails they join. To retain uniform pressure of the formation, the sleeper spacing is

therefore reduced at rail joints. This joint sleeper spacing may be obtained as follows.

Formula $Pb = \frac{\cdot 195Ps}{bldx}$ of para 1804 becomes by substituting the value of

$$x = 82\sqrt[4]{\frac{I}{\mu}} \text{ from para 704}$$

$$Pb = \frac{\cdot 01Ps}{bldx}\sqrt[4]{\frac{\mu}{I}}$$

From this it is evident that

Pb varies as s

and it also varies as

$$\sqrt[4]{\frac{1}{I}}$$

i.e., inversely as the fourth root of the moment of inertia.

For example, if I of the two fishplates is one-fourth that of the rail and the sleeper spacing is 33″, the joint sleeper spacing should be

$$33\sqrt[4]{\tfrac{1}{4}} = 23'', \text{ say.}$$

1807. Lateral strength of track

Lateral thrusts are exerted on the track by a vehicle due to several causes. Two of the important causes are inadequate balancing of locomotives (*vide* para 1708) and the centrifugal force on a curve.

The lateral thrust is countered mainly by friction between ballast and sleeper and which varies with the vertical load on the sleeper, and is assisted by downward projections in metal sleepers. The co-efficient of friction for wooden sleepers is 0.7.

The lateral strength of the track is governed chiefly by the depth of the ballast, its quality and sleeper spacing. It varies as $1/s^{3/4}$ where s is the sleeper spacing. The lateral strength may therefore be increased by reducing the sleeper spacing, namely, introducing additional sleepers.

Because of the vertical curve created in a rail as a wheel travels over it, the track in front as well as the back of a locomotive is lifted and the frictional force is reduced hence excessive nosing of the locomotive, particularly on a curve, may distort the track. Any

such tendency may be guarded against by closer sleeper spacing, heavier rails and adequate ballast depth.

From experiments it has been ascertained that the horizontal deflections caused by lateral thrusts disappear after the thrust is removed, when the thrust does not exceed a certain value. Beyond this critical thrust value the track is distorted. This critical value is taken by Blondel, an authority on the subject, as that obtained with a distortion of 4 m.m. or .16″ of the track. Based on this, the limit of safe lateral thrust is given as

$$40 \text{ per cent of axle load} + 2 \text{ tons}$$

The above percentage of axle load, in terms of which the safe horizontal thrust is considered, decreases with an increase in axle load. Blondel's limit is therefore not to be taken as a rigid value but mainly for comparison purposes. The actual lateral thrust exerted by a particular class of locomotive may be measured with strain gauges.

For example, the maximum lateral thrust exerted by the Indian B.G. passenger locomotive (WP class) has been found from tests under adverse conditions and with the wheels, axles and housing in a badly worn state (artificially produced) to be 9 tons at 60 m.p.h. and 10 tons at 70 m.p.h.

The axle load is 18.5 tons hence if the limit is based on percentage of axle load, the limiting value is

$$\left(\frac{40}{100} \times 18.5\right) + 2 = 9.5 \text{ tons.}$$

On the other hand, the lateral strength at failure of track with $n+3$ steel trough sleepers is 14.9 tons. The lateral strength if the density is $n+2$ works out to 14 tons based on the formula that lateral strength varies as $1/s^{3/4}$ In accordance with this, a steel trough sleeper track with a density of $n+2$ is adequate for locomotives of WP class.

It is necessary also to appreciate that

(1) The lateral thrust of a locomotive on a curved track is normally much greater than on a straight track and depends on the speed and superelevation. The sleeper density on curves should therefore be greater than on straight tracks.

(2) The worst condition for track distortion is the effect produced by a closely spaced group of axles, as the transverse loading on a short length of track is greater than that produced by a single axle and, at speed, the

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forces are applied at a given point on the rail within a fraction of a second.

(3) With wooden sleeper track, the spreading of gauge has also to be given consideration. It is reckoned that with a density of $n+3$, spread of gauge takes place if the lateral thrust exceeds 10 tons.

(4) Any resurfacing of the track reduces temporarily its lateral strength and speed restrictions are therefore necessary until the track has consolidated.

1808. Stresses in fishplates

For ideal conditions the deflection at the rail joint under a moving load should not exceed the deflection elsewhere of the solid rail. The stiffness of the rail joint is much less than the stiffness of the solid rail, but the deflection under static load or a load moving at slow speed is reduced by keeping the sleepers at the joint closer than elsewhere along the rail length. Under dynamic or fast moving loads, however, closer spacing of sleepers is not adequate to ensure uniform deflection.

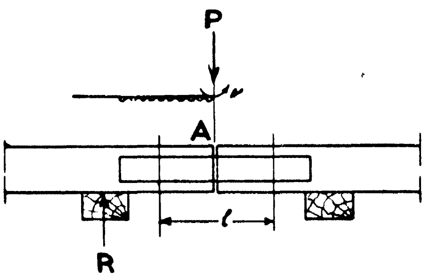

Fig. 1808

Positive bending moment occurs in a rail joint when the wheel load is directly over the joint. The positive moment in the fishplates is partially relieved by the rail ends also acting as cantilevers. When the joint is between two wheel loads, negative bending moment occurs in the fishplates. This negative moment has to be carried completely by the fishplates and is therefore more severe than the positive moment. This is the reason for most fishplate failure starting with a crack at the top centre of the fishplate.

In ascertaining stresses in fishplates the following points based on results of American experiments have to be given due consideration.

(1) For purposes of calculation a rail joint may be considered as developing about 85 per cent of the bending moment in the rail.

(2) Each of the two fishplates carries about 60 per cent of the bending moment at the joint.

(3) Fishplates bend vertically, namely, with the neutral axis horizontal, provided the fishing planes fit well and the fishbolts are sufficiently tight to take up lateral bending. Any looseness in the bolts results in the neutral axis becoming inclined to the horizontal and the resultant stresses in the fishplates are considerably increased.

(4) The location of the pressures exerted between the rail and fishplate are lengths of about 4″ along the top fishing plane at the centre of the fishplate and about 3″ lengths along the bottom fishing plane at the ends of the fishplate.

The shear in the fishplate is obtained by dividing the bending moment by the lever arm, namely, the distance between the centres of contact areas in the top and bottom fishing planes.

(5) The permissible stress in fishplates is taken as a very high percentage of the yield strength of the material. The reasons are that (i) looseness, poor fit and play between the fishbolts and their holes decreases considerably the magnitude of the bending moment in the fishplate. (ii) If the yield point is exceeded, the flow or plastic yield of metal partially relieves the stress and although the fishplate is slightly bent and the load on the joint sleepers increased, no dangerous conditions are likely to arise. A high yield strength in fishplate steel is therefore desirable. American specifications require for fishplates a yield point of at least 31 t.s.i.

The method of working out stresses in fishplates is to obtain the bending moment for rails (*vide* para 1801) and multiply by the factor .51 (=.85 × .6) to obtain the bending moment in each fishplate. The longitudinal stress is the bending moment divided by the modulus of section of the fishplate. The value obtained is on the assumption that the fishplates are tight and the fishplates bend vertically (*vide* item (3) above).

A more rational method has been presented as a result of Indian research, based on the principle of minimum strain energy. This gives lower stresses than the above method, the values being about 25 t.s.i. with 100 per cent impact allowance.

1809. Other deductions

Conclusions arrived at as a result of track research in India and which vitally concern maintenance men are :—

(1) Stresses in rails are considerably increased if the supporting sleepers are loose on the ballast, that is if they are not thoroughly packed.

(2) Increase in rail section does not reduce the pressure on the formation. If heavier loads are contemplated, both the rail section as well as the ballast depth and sleeper density should be checked.

(3) The heaviest wheel load can be sustained by a soil with poor bearing capacity provided the ballast depth is increased sufficiently and sleeper spacing is reduced suitably.

(4) The elasticity of a bed of ballast lies in the small voids between the ballast pieces, and for retaining suitable elasticity, which is necessary for the vertical stability of the track, the ballast should be kept clean by periodic screening.

(5) For carrying a certain load, the shape of sleepers is immaterial but for distributing the load on the formation an increase in the number of sleepers is more effective than an increase in the width of the sleepers.

(6) Consideration of the lateral strength of the track is essential to prevent the track being thrown out of the correct position or being distorted. The lateral strength (i) increases as the new or relaid track consolidates. (ii) It is also greater with sleepers which grip the ballast such as cast iron pot and steel trough sleepers than with wooden sleepers. (iii) It is increased considerably by spacing the sleepers closer together. (iv) Heaping up of ballast along the two ends of the sleepers does not help the lateral strength but helps to keep the packed ballast under the sleepers in position.

(7) If a track is not maintained in good condition, particularly in correct alignment and at correct level, the lateral strength is reduced.

(8) The greatest impact, namely sudden blows, occur at rail joints and increase the stresses considerably. It is therefore essential to keep the joints in as good a condition as possible.

Train Resistances

1901. Types of resistances

THE track has a considerable effect on the loads and speeds of trains and the hauling capacity of a locomotive.

As indicated in para 108, the adhesive force which depends on the weight on the driving wheels and the coefficient of friction between rails and wheels, is the governing factor. The tractive effort of the locomotive has to be greater than the adhesive force and has to be adequate to overcome various resistances offered to the movement of both locomotives and trains.

These resistances may be collected into groups as follows:—

(1) Resistance due to journal friction, rolling friction and track resistance. These resistances are grouped together as they are independent of speed.

(2) Resistance due to vertical and horizontal movements of locomotives and vehicles, which are dependent on track depressions, sleeper spacing, relative frequency of oscillations, flange friction, angle of infringement of bogie on rails, etc. These resistances vary as the first power of the speed.

(3) Atmospheric resistances due to the following effects on a vehicle moving at speed : Frontal pressure, rear suction, skin friction and effect of spaces between adjoining vehicles. These resistances vary with the square of the speed.

The above three resistances may conveniently be termed Train Resistances.

(4) Resistances caused by the track profile, namely gradients and curves.

(5) Resistance offered at starting and at accelerating.

(6) Wind resistance. This may be added to the above resistances, but is normally not taken into account unless there is a steady high wind from a particular direction on any lengths of track.

1902. Magnitude of various resistances

As variables in all the above types of resistances are numerous, elaborate computations which often need verification by tests, are necessary. Average approximate formulæ only are given here.

If all resistances are specified as fractions of the load W of the vehicles, the first three resistances, of para 1901, namely the train resistance R_t for vehicles may be covered by:

$$R_t = .0016\ W + .00013\ WV + .0000015\ WV^2$$

where V is the speed in m.p.h.

The corresponding resistances for a locomotive are slightly different.

$$\text{Resistance due to gradient} = \frac{W}{\text{gradient}}$$

Resistance due to curvature varies with the degree of curvature. With the limits fixed for rigid wheel bases and bogie wheel bases in India, curve resistance may be taken as

$$(.0004\ W \times \text{degree of curve})$$

for B.G. The co-efficients for M.G. and N.G. are .0003 and .0002 respectively.

Resistance at starting may very roughly be taken as .01 W for a locomotive and .005 W for vehicles.

Resistance due to acceleration is given by

$$.05\left(\frac{V_2 - V_1}{t}\right)W$$

where V_1 and V_2 are velocities in m.p.h. at the beginning and end of time t.

Wind resistance depends on the angle at which it impinges on the train. If its component impinging broadside on the train is v m.p.h., the wind resistance may be taken as

$$.000004\ av^2$$

where a is the broadside area of the train.

It will be appreciated that all resistances do not act together, and all the values are not cumulative.

1903. Effect of resistances due to track profile

The effect of track profile on the hauling capacity of a locomotive may be appreciated through an example.

Assuming that a B.G. locomotive has three pairs of driving wheels and the load on each pair of wheels is 20 tons, and the coefficient of friction between wheels and rails is 1/6 the load which it can haul over a level, straight track at 60 m.p.h. the adhesive force is ascertained as follows:—

The adhesive force $= 1/6 \times 3 \times 20 = 10$ tons

The weight W which it can pull on a straight and level track at 60 m.p.h. is:

$$10 = .0016\,W + (.00013 \times 60)\,W + (.0000015 \times 3600)\,W$$

hence W = 675 tons.

If this locomotive runs on a section with a ruling gradient of 1 in 160 and with maximum 6° curves, the drop in speed is obtained as follows.

As grade compensation is provided on curves, even if the 6° curve happens to be located on a 1 in 150 grade, the resistance of both grade and curve need not be considered simultaneously. The grade reaction is invariably more severe than curve reaction.

The reduction in speed on a 1 in 150 grade is:

$$10 = (.0016 \times 675) + (.00013 \times 675)V + (.0000015 \times 675)V^2 + \frac{675}{150}$$

$$.001V^2 + .088V = 4.42$$

$$V = 36 \text{ m.p.h.}$$

The speed reduction on a 6° curve is:—

$$10 = (.0016 \times 675) + (.00013 \times 675)\,V + (.0000015 \times 675)\,V^2 + .0004 \times 6 \times 675$$

$$.001\,V^2 + \cdot 088\,V = 7.3$$

$$V = 53 \text{ m.p.h.}$$

If the speed on a level straight track is reduced to 40 m.p.h., the load which the same locomotive can haul is:

$$10 = .0016\,W + (.00015 \times 40)\,W + (.0000015 \times 1600)\,W$$

hence $W = 1087$ tons

This is over 400 tons more than at 60 m.p.h. speed. This indicates one of the reasons for slower speeds of goods trains.

Basis of Investigations

2001. Possible causes of derailments*

PART of the normal duties of track maintenance staff is to investigate the causes of derailments of vehicles and locomotives with a view to preventing their recurrence. A knowledge of the possible causes of derailments is therefore essential.

The three fundamental points to be remembered are:—

(1) The vehicle and the track on which it runs are to be considered as one unit in appreciating causes and effects.

(2) Derailments often result from a combination of minor defects both in the vehicle and the track, whilst a derailment may not occur with a major defect if other conditions are favourable.

(3) The fact that (i) a vehicle has run over a considerable distance without mishap or (ii) that all vehicles except those derailed passed over a certain section of the track does not prove that (*a*) the cause of derailment lies elsewhere than in the vehicle in the first case, and (*b*) the cause is other than defective track.

For simplification, possible causes of derailments may be divided into three groups:

(1) Track defects,

(2) Vehicle defects, and

(3) Operational defects.

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*Paras 2001 to 2004 are based on a paper by Mr. A. Saldanha and Mr. O. S. Murthy, published in the *Journal* of the Bombay and Western India Section of the Permanent Way Institute.

2002. Track defects

If the vehicle is disturbed from its position of equilibrium, the springs of the vehicle due to inertia do not act instantaneously to set this right and a rolling motion is set up in the vehicle. This results in an increase and decrease in the load exerted by the wheels. The magnitude of this alteration in wheel load depends on several factors such as speed and on the characteristics of the springs. If the variation in the load on the wheels is large enough, the wheel flange may rise above rail head and derail.

A vehicle may be disturbed from its position of equilibrium due to one or more of the following four track defects:

(1) defective cross levels,
(2) defective alignment,
(3) defective gauge, and
(4) low joints.

Exact limits cannot be specified for such defects and it must be appreciated that a perfect track, namely, without the slightest variation in cross levels, alignment and gauge is not a practical possibility. A difference of $\frac{1}{2}''$ may be considered as the limit for cross levels.

On curved tracks, deficient superelevation is not a vital factor provided this defect is not combined with one or more of the four track defects already mentioned. The reason is that although due to deficient superelevation the lateral thrust increases, the load on the outer wheels also increases proportionately and prevents the wheel from climbing the rail. In case of excessive superelevation there is a possibility when a vehicle is moving at a low speed for the outer wheel being relieved of its load to such an extent as to cause derailment by mounting.

It may be mentioned that a vehicle moving over a curved track has to be constantly swivelled round a point called the centre of friction and a curving force is necessary to do this even at the lowest speed. This curving force is supplied by the pressure of the flange of the leading wheel against the rail. The outer rail on a curve has therefore to withstand this additional curving force.

Obstructions on the track through any cause can lead to derailments.

Derailments over turnouts may be caused by:

(1) Gaping points. Gaping may be due to (i) a bent tongue rail which may have been forced open in the trailing

direction, (ii) wrongly adjusted heel bolts, and (iii) an obstruction such as a stone between the tongue and stock rails which may be undetected even with interlocked points due to loss of lever movement.

(2) Lifting of toe of switch due to badly packed sleepers under the heel and loose heel bolts.

(3) Improper assembly of crossing, loose crossing bolts or wing rails higher than the crossing nose. The wheel tyre under such conditions may get wedged between the two wing rails and force them apart.

(4) Excessive wear in switches with the resulting flow of metal preventing the proper setting of the switch.

(5) Tight gauge and defective check clearances at the nose of crossing may result in a new wheel mounting the nose.

2003. Vehicle defects

The bearing spring of a vehicle permits the wheel to follow irregularities in the rail in the vertical direction upto the limit of its static deflection. When this limit is reached the wheel is relieved of its imposed load and may mount the rail. The static deflection of the spring of an empty wagon is about ½″ whilst that of a locomotive spring with a light load may be 1″. Defective springs can be detected by measuring the camber when the vehicle is empty. Broken spring plates reduce the stiffness of the spring considerably whilst broken links or shackles relieve the wheel completely of its load. Whilst excessively stiff springs are dangerous due to the static deflection being very small, excessively flexible springs are equally troublesome as rolling is set up in the vehicle and if this is excessive, the wheel may be lifted off the rail through horn stays. Due to considerable variation of load in tank locomotives and tenders of locomotives, the spring deflection may be as little as ⅝″ when empty whilst it may be 1½″, which is the permissible limit, when full. This variation is a source of possible trouble.

Underframes bent through buffing shocks, to which vehicles are subjected, may cause uneven loading of wheels and such vehicles are liable to derailment. Any variation in the height of the buffers is an indication of this although uneven loading may be present without this variation and the only method of ascertaining this is to place the vehicle on a locomotive weighing machine.

Broken axle boxes or broken axles lead to derailment.

Although the load on various wheels of a locomotive depends on the centre of gravity of the locomotive and compensating beams are not intended to alter this, it is possible for a wheel to be completely unloaded if the wrong type of spring is introduced or the length of the spring hangers is altered. Possibilities of derailment are great and the only method of detecting this is with the help of a locomotive weighing machine.

When a vehicle moves over a curved track, the outer leading wheel has a tendency to cut into the side of the outer rail. If the tyre profile is worn the upward frictional force may be sufficient to cause the wheel to mount the rail and derail.

The flange forces exerted by the wheels of a locomotive depend partly on its state of maintenance. The leading bogie or pony truck guides the locomotive round a curve by exerting a transverse force on the locomotive frame through horizontal control springs. If these springs are defective insufficient curving force is exerted and excessive flange pressure are caused by the leading driving wheels, which may result in a derailment. Incorrect adjustment of control springs or excessive clearances may derail the leading bogie wheels. Worn flanges of leading coupled (driving) wheels result in excessive flange forces on the next coupled wheels as the lever arm about the centre of rotation is reduced. Although flange clearances for these wheels is normally kept larger than for the leading wheels, possibilities of derailment of these wheels due to worn flanges of the leading coupled wheels exist.

When a locomotive is running tender foremost, the bogie control springs instead of exerting a curving force, introduce an anti-curving force and at high speed the trailing coupled wheels (which in the reverse movement become the leading coupled wheels) are liable to derail. This is the reason for the speed of locomotives moving tender foremost being severely restricted.

If the draw gear between the locomotive and its tender is very stiff, an anti-curving force is exerted by the tender which may result in derailment.

Defective buffers, or a variation in height of buffers of adjacent wagons causing them to interlock, may result in derailment.

Sharp wheel flanges are a possible cause of derailment at facing points. False flanges on tyres, namely ridges which are produced near the outer edge of the tread due to wear of tread, may force switches open when moving in the trailing direction.

A point to be remembered is that a defect observed in the track or in the vehicle after derailment may not necessarily be the cause of the derailment but may be the result of the derailment.

2004. Operational defects

A railway vehicle is prevented from coming off the rails by wheel flanges. On account of the clearances between the wheel flanges and the rail, there is a side-to-side movement or lateral oscillation of the axle, this movement being governed by the coning of the wheels, the height of centre of gravity and the length of rigid wheel base of the vehicle. At speed, the amplitude of lateral oscillation keeps on increasing. This building up of lateral oscillation may result in excessive rolling and track distortion. The lateral oscillation is greatest when the draw bar pull is the least, namely, when a train is coasting along a falling grade with the steam shut off.

With any defect either in the track, such as defective cross levels, alignment, etc., or in the vehicle, such as excessive play in the axle boxes, worn tyres, etc., the lateral impact increases rapidly with speed and may result in dangerous conditions.

A vehicle adequately sprung can negotiate an irregular path without trouble if it is moved at a slow speed as the greater time interval permits sudden changes in direction and recovery in spring movement. At speed this is not possible and derailment may take place. Compliance with speed restrictions should therefore be rigidly enforced.

Careful application of brakes and opening of the regulator are essential requirements in train operation. If brakes are suddenly applied the train is put in a state of compression due to inertia of the vehicles acting in one direction and the braking effect in the opposite direction. The resulting compression may be sufficient to lift a light or empty wagon off the rails.

For hauling vehicles, the pull is applied at the coupling which is at a higher level than the plane of vehicle resistance at the rail level. This results in a couple. The sudden opening of regulator may cause the trailing wheels of a light wagon to be lifted up. Sudden opening of the regulator may also result in a broken coupling.

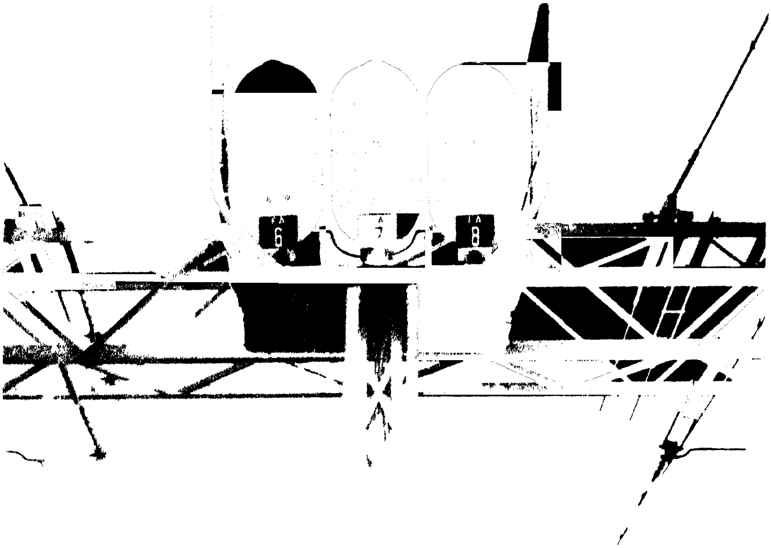
Uninterlocked points are liable to open slightly unless the point lever is held in position by the operator.

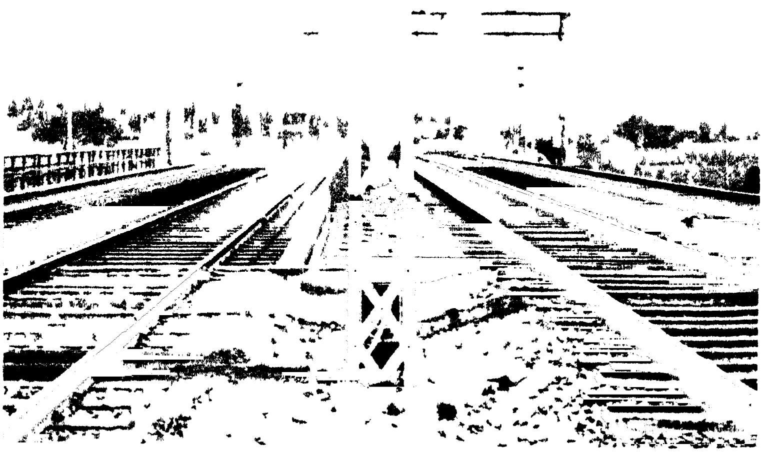
Defective distribution of load in a vehicle resulting in unequal weights on the wheels is another cause of derailment when combined with other defects.

With both the track and the vehicles to existing Indian designs in a satisfactory condition, excessive speed by itself, however, does not lead to derailments on a straight track.

PART 5

Ancillary Subjects





Colour light signals on electrified track

Manufacture and Test of Track Materials

2101. Composition of iron and steel

IT is very necessary for a track man to know the quality and strength of the materials with which he has to work. There are several types of steel used on railways and it is necessary, without going deeply into the metallurgy of iron and steel, to know how these differ from one another and what qualities they possess. It is also essential for the materials to be thoroughly tested before use, as the safety of those using the railways depends on the quality of materials.

Cast iron and steel are compositions of iron with small quantities of carbon, manganese, silicon, sulphur and phosphorus. Of these, carbon, manganese, and silicon are necessary elements whilst sulphur and phosphorus are undesirable. Although the percentage of carbon is relatively small (not more than 5% in cast iron and not more than 1.7% in steel) the ultimate tensile strength and elasticity of the metal depends on the carbon. An increase in the carbon content, increases the hardness of the metal, but also makes it more brittle. Steel containing less than 0.3% carbon is called *mild steel.* Steel, with a carbon content between 0.3% to

0.6%, is known as *medium carbon steel* and that with over 0.6% carbon, *high carbon steel*. Manganese makes the metal more resistant to abrasive action and also increases its elasticity and strength, whilst silicon removes the gaseous impurities and makes the metal dense. Phosphorus and sulphur are undesirable, as the former makes the metal brittle and the latter cracks the steel during hot rolling. The properties of cast iron and steel are affected, not only by the percentage of the carbon present, but also by the effect of this carbon on the internal structure of the material at different temperatures.

The composition of various steels used in the track and of cast iron are given below. The composition may vary with the process of manufacture of steel and the table gives the composition for steel manufactured by the Basic open hearth or Duplex processes.

Percentage of	Indian Steel and Cast Iron				British specification rail steel	American specification rail steel
	Steel for rails	Steel for fishplates	Steel for sleepers	Cast iron		
Carbon	0.55 to 0.68	0.30 to 0.42	0.15 to 0.35	3.50	0.55 to 0.60	0.62 to 0.83
Manganese	0.65 to 0.90	below 0.80	0.70	1.00	0.70 to 0.90	0.50 to 0.90
Silicon	above 0.05	below 0.15	0	1.50	0.10 to 0.30	above 0.15
Sulphur	below 0.05	below 0.06	below 0.06	below 0.05	below 0.06	—
Phosphorus	below 0.05	below 0.06	below 0.06	below 0.35	below 0.05	below 0.04

2102. Manufacture of iron and steel

The ores from which iron and steel are manufactured are haematite (Fe_2O_3), magnetite (Fe_3O_4) and siderite ($FeCO_3$). The ores which contain more than 16% iron, are known as *high grade ores*. Iron is obtained from the ore by removing the oxygen and the impurities. Carbon in the shape of coke is used both as fuel and as a deoxidiser. Limestone is employed as a *flux* for removing impurities. It combines with the impurities and forms a fused mixture known as *slag*. Iron is manufactured in a tall structure called a *blast furnace*. Its height is generally 3½ to 5 times the diameter of the hearth at the base and it is lined with firebricks. Iron ore, coke and limestone are placed in the blast furnace from the top in alternate layers. The heat is imparted by hot air, from a series of stoves, blown into the furnace near its base, through

pipes called *tuyeres* and also from the charge of coke in the furnace. The hot gases from the furnace are returned to the stoves to economise fuel. The ore melts and the impurities combine with the limestone to form slag, which floats on top of the molten metal. The molten metal is drawn off near the base of the hearth from time to time, and the slag is also removed periodically through suitable openings near the top of the hearth. The molten metal is taken in huge ladles to the steel plant, or is poured into moulds in which it solidifies. In the latter case it is known as *pig iron*.

The coke for the blast furnace is obtained by crushing coal and heating it in long horizontal ovens. Many by-products such as tar, hydrocarbon oils and ammonia are obtained and the coal gas is used for supplying the heat for conversion of coal into coke.

The slag when broken can be used as ballast. If a stream of water is directed on hot slag, it becomes granulated and this is sometimes used for making cement or as lightweight aggregate for concrete.

The proportion of ore, coke and limestone used, depends on the quality of ore. In India, about 1,650 tons of ore, from certain quarries and mines, are required for 1,000 tons of pig iron. The quantities of fuel and flux necessary are 1,000 tons coke and 500 tons limestone. The percentage of coke obtained from coal is about 75%.

Steel is obtained from pig iron by reducing the carbon content and adjusting the composition of other elements in the pig iron.

There are a number of processes by which steel is manufactured from pig iron. The processes generally employed are Open hearth, Bessemer and Duplex. The Bessemer is a quick process, whilst the Open hearth is a very much slower process. On the other hand, there is greater uniformity in steel made by the Open hearth process. The Open hearth and Bessemer processes are sub-divided into basic and acid processes. The Duplex method is a combination of Bessemer and Open hearth processes, and combines the rapidity of the Bessemer process with the uniformity in metal of the Open hearth process.

In India, the Open hearth and the Duplex processes are used for manufacturing rail steel. Other processes also exist, such as the Crucible process for tool steel and the Electric process, in which heat is derived from electricity. The use of rails made in Europe by the Thomas process which is a basic Bessemer process, was not favoured in India but the defects, to which these rails were liable, have been eliminated to a very great extent and such rails are now in use in the country. Its chemical composition in

accordance with the International Union of Railways (U.I.C.) is as follows: carbon 0.40 to 0.55, manganese 0.70 to 1.20, silicon 0.10 to 0.30, sulphur 0 to 0.06 and phosphorus 0 to 0.08.

In the *Bessemer process*, a furnace of the shape of a pear and called a *Converter*, is filled with molten pig iron and air is blown through it. This removes the carbon by oxidation and the manganese and silicon through the slag. As more carbon is removed than is desirable, the metal has to be recarburised. The colour and height of the flame, emitted from the opening at the top of the converter, indicates when the reaction is complete. The air blast is then cut off and metal is poured into ladles, additions of alloys, in a molten state, being made in case of alloy steels. The *acid process* differs from the *basic process* in the lining used in the converter. The lining in acid process is usually ganister, whilst in the basic process, it is magnesite. The undesirable elements, phosphorus and sulphur, are not removed in the acid process. Sulphur cannot be removed in the basic process.

In the *Open hearth process*, a shallow hearth lined with suitable bricks and roofed with a brick arch is used. Suitable openings are left for introducing the metal and the gaseous fuel, and for drawing off the molten steel. As in the case of Bessemer process, the type of lining determines whether the process is basic or acid and the metal has also to be recarburised. In the basic process, calcined limestone is added for the removal of phosphorus and a slag forms on the surface. The 'charge' is frequently tested by taking out a small quantity in a hand ladle and examining the sample. When the requisite condition is obtained, the metal is drawn off, various ferro-alloys being added during this process. Poor qualities of pig iron, containing a relatively high percentage of phosphorus, can be treated successfully by the basic open hearth process.

In the *Duplex process*, the impurities in molten pig iron are rapidly oxidised in Acid Bessemer converters and the metal is then poured into basic open hearth furnaces where the phosphorus is removed.

The molten steel, obtained by any of the processes, is conveyed in large ladles and poured into Ingot moulds. When the steel has set, the moulds are stripped. The *ingots* are taken to a furnace, known as a Soaking pit, where the temperature throughout the ingot is equalised. The ingots are from 12″ to 36″ square, from 4′ to 8′ long and may easily weigh 5 to 10 tons. The ingots are taken from the soaking pits to the Blooming mill, where they are rolled into blooms of required sizes. *Blooms* are usually about

8 inches square and small blooms are known as *billets*. The ends of the blooms are cropped, i.e., a certain length is cut off from the ends. The blooms are again heated in reheating furnaces, for equalising the temperature throughout the metal. They are passed through a series of rolls in a rolling mill, the rolls being so shaped and set at such distances, that the metal takes the desired shape of rail, angle iron, flat iron, etc. A large number of passes through the rolling mill, with a smaller decrease in section per pass, produces sounder steel than a fewer number of passes, with larger decrease of section per pass.

After the last pass, the rail, whilst still hot, is cut to proper length with a power saw. It is then taken to a *hot bank* where it is allowed to cool. As the shrinkage of the thicker head is greater than that of the base, the rail becomes concave. The concavity is partly reduced by turning the rails on the hot banks, so that its base is on top and its weight thus helps in removing the sag. The rail is then passed through a straightening machine and the bolt holes are drilled.

Although the quality of steel depends on its chemical composition, the process of manufacture also has a considerable effect on its properties. A homogeneous ingot is essential and to attain this, the top portion of the ingot is discarded as it is likely to contain blow holes, segregated material and piping. It has been found that if blooms, instead of being taken direct to the blooming mill, are allowed to cool and are then heated to the requisite temperature, the tendency to the formation of shatter cracks and transverse fissures is reduced.

2103. Strength and test of rail steel

The tensile strength of carbon rail steel is 50 to 55 tons per square inch, compared to about 30 tons per square inch of mild steel. As it is essential that steel for every rail should be of the best quality, elaborate inspection and tests of the steel are carried out, both during and after manufacture. The tests may be conveniently divided into three categories—visual, chemical and mechanical.

1. *Visual inspection :* Before rolling commences, the gauges are checked. Whilst the rails are being rolled, pieces are frequently cut and examined, to see that the section is correct. A detailed inspection of every finished rail is carried out, the head, web, foot and ends being thoroughly examined. The correctness of the bolt holes, the straightness of the rail, the length, the section, the

correct fit for fishplates are checked and acceptance or rejection marks stamped on each rail.

The following tolerances are permitted: $\pm\frac{1}{4}''$ in length, $+1/32''$ or $-1/64''$ in height, $\pm 1/32''$ in width of the foot. A reverse camber (namely with the ends higher than the centre) of $\frac{7}{8}''$ for 42′ and $\frac{3}{4}''$ for 39′ rails, is permitted.

2. *Chemical tests:* The composition of each charge of steel is examined by a Metallurgist. Samples are taken of molten metal and subsequently analysed. Rail sections are pickled in acid to trace any fault. Drillings are taken from test pieces and analysed. A piece of rail is cut from each cast and tested.

3. *Mechanical tests:*

(*i*). A *tup*, or *drop test* is carried out on a piece of rail, rolled from metal from the top of the ingot from every cast. The test piece, 5′ in length, is placed with its head upwards, on supports 3′ to 4′ apart. A weight, or tup, is dropped from a prescribed height as given in the table below. The rail must not fracture or crack under one blow. The test piece is taken from the first rail rolled from an ingot, as possibilities of defects in the first rail are greater than in other rails. The first rail from the top of an ingot is branded with a star and the last rail from the bottom of the ingot is marked with a circle.

Weight of rail in lbs. per yard ..	115	90	75	60	50
Distance between supports of test piece in feet	4	3.5	3.5	3	3
Weight of tup in tons	1.25	1	1	0.75	0.75
Height in feet from which dropped ..	27.5	23.5	19.5	18	15

A similar tup test for welded rail joints has been suggested. The weight of tup and height of drop in a 90R rail joint has been tentatively given as 5 cwts. and 12′ respectively.

(*ii*). In order to trace any flaw at the junction of the web and foot of a rail, a *hammer test* is carried out during manufacture. The foot of a test piece, 2 inches long, is held rigidly in the vertical position and the web of the rail is struck with a 10-lb. hammer. The test is carried out on two identical test pieces, the hammer being struck on the opposite faces.

The above tests are used on Indian railways. Various other tests are used in different countries but the tup test appears to be common in most countries. In America, the tup is 2,000 lbs. in weight and is dropped from a height varying from 18′ to 23′, for rails of sections 81 lbs. to 140 lbs. The test pieces are 4′ to 6′ long and are supported at 3′ to 4′ centres, with their head downwards.

2104. Alloy steels for rails

Alloy steels have ingredients in addition to those in the normal composition specified in para 2101, and each of these special ingredients gives a particular quality to the steel.

Alloy steels are costly and are used only at special locations, such as points and crossings and sharp curves.

Following are a few of the alloy steels which are used for manufacturing rails.

Medium manganese steel.

High manganese steel.

Chromium steel.

Nickel-chrome steel.

Of these, medium manganese is the most commonly employed alloy steel in India. Alloy steels are obtained by the usual method of steel manufacture, the specified percentage of the alloy being added during manufacture.

Medium manganese rails, containing 1.1% to 1.4% manganese, 0.45% to 0.55% carbon, not less than 0.05% silicon, not more than 0.05% phosphorus and not more than 0.05% sulphur, are used for fabricating points and crossings.

High manganese steel has a life of, as much as, ten times that of medium carbon steel, but it is very expensive and is used for fabricating points and crossings over which very heavy traffic passes. The manganese content varies from 10.5% to 15.0% and the carbon content from 0.95% to 1.35%.

The use of *chromium steel* containing 0.75% to 1.0% chromium, 0.65% to 0.85% manganese, and 0.42% to 0.53% carbon, has been abandoned in India in favour of medium manganese steel.

Resistance to wear has been considerably increased in America by using control cooled high carbon steel, reheating and quenching in oil. A manganese-chrome-vanadium steel has also been

evolved, the wearing qualities of which are far superior to normal rail steel.

2105. Heat treatment of steel

The properties of steel are considerably altered by subjecting the steel to controlled heating and cooling. Iron and carbon are present in steel in different forms of crystalline atomic structure and these forms are altered at certain temperatures known as *critical points.* When steel is heated, its temperature rises, as it absorbs more and more heat. When the temperature reaches the critical point which varies with the composition of steel, the metal ceases to rise in temperature with further absorption of heat and the heat is used up in the transformation of the crystalline atomic structure. After further heating, the temperature continues to rise, until at another critical point, the temperature again ceases to rise. There are normally three critical points in steel, but these may be reduced to two or one, by variation in the chemical composition of the steel. The temperatures of the critical points are also altered by variations in the quantity of carbon and by additions of alloys. Some of the forms in which the aggregate of iron and carbon exist in steel are ferrite, perlite, fine perlite, cementite, austenite and martensite. By heating the steel to predetermined temperatures and subsequent cooling at predetermined rates, its strength and other properties can be considerably altered.

The *hardening* process is a form of treatment for obtaining steel of great strength. In this treatment, the steel is heated to the upper critical point and then quenched in oil, water or brine. As this process makes the steel brittle, it is tempered to relieve the quenching stresses and make it less brittle. In *annealing,* which is done for obtaining a soft steel, the steel is heated to just above the first critical point and kept at that temperature for some time. It is then allowed to cool as slowly as possible. *Normalising* produces fine grain steel with great toughness and this process is used for structural steel. The steel is heated gradually to the first critical point, then rapidly to the highest or third critical point and then cooled gradually in air, but at a rate greater than that for annealing. The different treatments produce steel with very different characteristics. In heat treatment of rails, either the whole rail, or the head only, or the ends of rails may be treated. Heat treated rails resist wear better than untreated rails and the life of the rail is increased.

Different methods of heat treatment are known by various names, e.g., Sandberg process, Brunorizing process, etc. It may be added that Sorbitic heat treatment practised in Britain gives

considerably increased resistance to abrasive wear at a small additional cost but has been found to develop irregular surface hardening when in use resulting in noisy running.

2106. Steel for fishplates

The composition of steel for fishplates is given in para 2101. Two classes of steel are used; class A has a tensile strength of 28 to 35 tons per sq. in., whilst class B, for which the chemical composition is given, has a strength of 36 to 42 tons per sq. in.

Fishplates are subjected to tensile and bending tests in addition to the chemical test. The tensile strength should be as given above with a minimum elongation of 20%.

In the bending test, the fishplate, when bent between bolt holes to 120°, the internal radius of the bend being not more than twice the plate thickness, must not show signs of fracture. If a fishplate has flanges, these are cut before the test is made.

No tolerance is allowed in the distance of bolt holes, which are drilled or punched, but a tolerance of + 1/32″ in the diameter of the holes is permitted.

Tolerance in weight is limited to $\pm$ 2%. Fishplates, after manufacture, are dipped in hot boiled linseed oil. Markings on fishplates are not very different to those on rails. On junction or combination fishplates, additional markings, IR and OR, signify inside and outside right respectively, whilst IL and OL indicate inside and outside left.

2107. Steel for fishbolts

The steel for fishbolts does not contain more than 0.60% of sulphur or phosphorus. Its tensile strength varies from 35 to 42 tons per sq. in. and the elongation from 18% to 25%.

Tensile, bending and unscrewing tests are carried out. In the bend test, the bolt should be capable of being bent cold through 180° round a bar of diameter equal to that of the bolt shank.

In the unscrewing test, the nut is screwed on to the fishbolt until it is flush with the end of the fishbolt. A 10-lb. spanner is fixed horizontally to the nut and weighed at a distance of 3′ from the nut with weights varying with the diameter of the bolt. The minimum and the maximum weights which the nut should carry must be within the limits given in the following table. The test is

repeated with the nut screwed four threads beyond the end of the fishbolt.

Diameter of fishbolt ..	$\frac{3}{4}''$	$\frac{13}{16}''$ to $\frac{7}{8}''$	$\frac{7}{8}''$ to $1''$	$1\frac{1}{8}''$
Minimum weight in lbs. ..	3	4	5	6
Maximum weight in lbs. ..	15	20	25	30

2108. Steel for sleepers

The billet for making steel sleepers is passed through a series of rolls until the required thickness is obtained. It is then cut into requisite lengths. These are heated, pressed to the prescribed shape in a hydraulic press and dipped in a hot solution made of 3 parts coal tar and 1 part tar oil. The composition of sleeper steel is also given in para 2101 and its tensile strength is 26 to 33 tons per sq. in. Steel sleepers must be free from cracks, flaws and pitting.

Tests similar to those for fishplates are carried out. For the bending test, a strip not less than 12″ long and $1\frac{1}{2}''$ wide is cut and bent, so that when the sides are parallel and the internal diameter is not greater than $1\frac{1}{2}$ times the thickness of steel, no signs of fracture appear.

Due to variation in contraction, whilst cooling, after they are pressed, a minute variation occurs in the gauge. The tolerances permitted are $\pm 1/16''$ in gauge, $\pm 2\frac{1}{2}\%$ in weight, $\pm 1/16''$ in the gap between lugs in the pressed up lug type, and $\pm 1/64''$ dia. in holes in the movable jaw type sleepers.

2109. Cast iron for sleepers

Cast iron is obtained by melting pig iron in a cupola, which is a form of miniature blast furnace. The molten metal is poured into moulds of loam or sand and castings of the required shape are obtained. The chemical composition of cast iron is given in para 2101. Cast iron is tested by means of test pieces 3′-6″ long, 2″ wide, and 1″ thick. The test piece is placed on edge, on supports 3′ apart and a load of $1\frac{1}{2}$ tons is placed at the centre. The test piece must not fracture and must deflect at least 0.3″ before rupture. A falling weight test is also carried out, in which a cylindrical weight of 0.143 ton is dropped from a height of 7′, three-times, after an initial drop of 3′ for bedding the pot or plate (the corresponding figures for M.G. sleepers are 5′ and 2′). The pot or plate is laid on a 2′ bed of sand with a rigid foundation

underneath the sand; a piece of rail 18″ long is fixed to the sleeper on which the weight is dropped. The pot or plate must not fracture under this test.

The metal in the sleeper should be free from cracks, blow holes and sponginess, and the size, shape and position of the jaws should be correct. A tolerance of $\pm 1/32''$ is allowed between the keying surfaces of jaws. When the pots or plates are assembled, the variation permitted in the gauge is $\pm 1/16''$. A difference of $\pm 5\%$ in weight is also permitted.

2110. Wrought iron

Wrought iron is the purest form of iron, with hardly any carbon in it, the percentage being as low as 0.02%. Manganese and sulphur are also present in about the same proportion. Whilst an analysis shows a high percentage of phosphorus and silicon, these form part of the particles of slag which is present in wrought iron and therefore do not make the metal brittle. Wrought iron presents a fibrous structure, in contrast to the crystalline structure of steel. It is malleable and ductile, resists shock and does not easily corrode. There are several ways of manufacturing wrought iron.

The process by which it is obtained, by the refining of pig iron, consists of melting pig iron in a puddling furnace, removing particles of pasty iron, which separate, squeezing out the slag and rolling into the required shapes.

Wrought iron is used for track accessories but on a small scale. Many articles, such as tie bars for sleepers, which were formerly made of wrought iron, are now made of mild steel.

General

2201. Tools and plant

FOLLOWING is a list of tools in common use for track maintenance:—

1. Beaters
2. Shovels
3. Phowras
4. Crowbars
5. Claw bars
6. Steel baskets
7. Ballast forks
8. Augers
9. Pick axes
10. Spike hammers
11. Sledge hammers
12. Fishbolt spanners
13. Ballast screens
14. Spike extractors
15. Track gauges
16. Track levels and cant boards
17. Rail tongs
18. Adzes
19. Chisels
20. Saws
21. Track levers
22. Track jacks
23. Jim crows
24. Ratchet braces
25. Tie tampers

Tools and plant and devices for special purposes used in India include :—

1. Rail carriers
2. Rail layers
3. Track braces
4. Rail pullers
5. Rivet busters
6. Hand-propelled trollies
7. Motor trollies
8. Material lorries
9. Bulldozers
10. Electric welding plants
11. Oxy-acetylene welding sets
12. Oxy-acetylene cutting sets
13. Centrifugal pumps
14. Air compressors
15. Winches, block and tackle, derricks, etc.
16. Mobile jib cranes
17. Drag line excavators
18. Rail lubricators

Extracts from Indian Railway specifications for track tools are given on Appendix 15.

Tools and plant common in American track practice, but not in use in India, are :—

1. Pneumatic augers
2. Pneumatic drills
3. Pneumatic nut fasteners
4. Power sleeper cutters
5. Spike drivers
6. Track liners
7. Rail expanders
8. Graders
9. Spreaders
10. Grading ploughs
11. Scrapers
12. Ditchers
13. Track raising machines
14. Weed killers
15. Ballast cleaners
16. Ballast shapers
17. Rail cutters

With the rising cost of labour in India, adoption on an increasing scale of mechanical equipment for maintenance of track is recommended. An analysis of the economics of the use of certain tools such as (1) spike puller, (2) bolt tightener, (3) rail drill, (4) rail saw, and (5) spike driver indicated that under American conditions, the above tools showed a saving as compared with manual methods after use for a certain number of minimum days as follows :—

(1) and (2)	8 days
(3) and (4)	2 days, and
(5) ..	12 days

The savings are therefore substantial. It will be appreciated that the cost of the same type of manual work remains unchanged (wage scale, etc. being considered as constant) whereas the unit cost with machines varies inversely with the number of days for which the machine is used.

2202. Trollies and lorries

Due to the long distances involved, inspection of the track is normally carried out from hand-propelled or *push trollies*. A push trolly consists of a light frame mounted on two axles. The trollies are pushed by two men at a time. A bench or cane chairs are placed on the frame. The seats should be kept as low as possible for proper observation of the track. Push trollies are easily removed from the track. In some cases, the frame is removed separately from the wheels and axles. In other cases, the trolly is lifted bodily off the track. There are advantages and disadvantages in both methods, but the second method is slightly quicker for removing the trolly in an emergency.

Motor trollies are used for more extensive inspections. There are two distinct types in use in India. The Anderson type (Fig. 2202) has a light motor cycle engine attached to one side of an ordinary trolly frame. The engine is connected to one of the back wheels with a V-shaped belt. As the engine, the frame and the axles can be separated quickly, this motor trolly is very easy to handle. In the other type, also extensively used in India, the wheels and axles are not detachable from the frame. The engine is fixed in a frame of its own and can be detached from the trolly. These trollies are sturdier but are difficult to handle and transport.

Material lorries, as the name implies, are used for transporting track materials such as sleepers, rails, etc. They are similar to push trollies but are stronger and heavier. They are propelled in the same way as push trollies.

2203. Welding

Welding is a method of uniting two pieces of similar metals, or of adding extra metal to build up an existing piece of metal. Welding may be broadly divided into Fusion welding, Resistance welding and Forge welding. In *Forge welding*, normally employed by blacksmiths, the metal is heated to a temperature, at which it becomes plastic, and the two pieces hammered together. In *Resistance welding*, heat is generated in the pieces of metal electrically and when pressure is applied, the two pieces are joined together. In *Fusion welding*, which is the type of welding most commonly used in steel work, two pieces of metal are melted so that they flow together and form a homogenous mass. The fusion of the metal may be brought about by heat generated by gases under pressure or by an electric current. In oxy-acetylene welding, oxygen and acetylene, both under pressure, are combined and ignited. A flame with a very high temperature is produced,

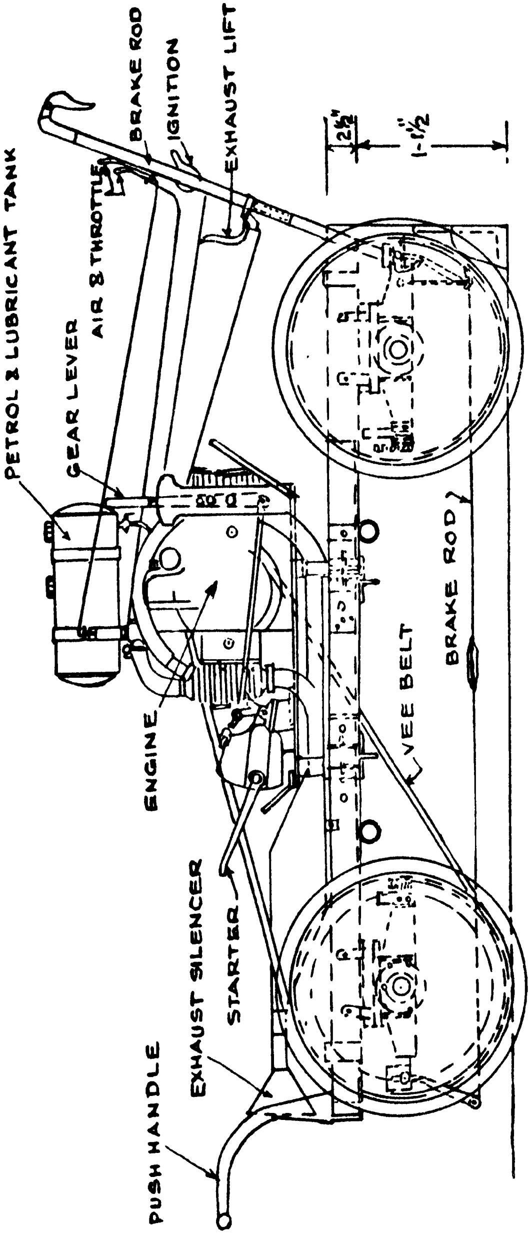

PETROL & LUBRICANT TANK
GEAR LEVER
AIR & THROTTLE
BRAKE ROD
IGNITION
EXHAUST LIFT
2½"
1-1½"
ENGINE
VEE BELT
BRAKE ROD
STARTER
EXHAUST SILENCER
PUSH HANDLE

Fig. 2202

which melts the parent metal as well as the rods of metal, called *electrodes*, to be deposited. The oxygen and acetylene are stored under pressure in portable cylinders. The cylinders are connected, through regulating valves and flexible tubes, to a blow pipe where the gases are combined and the flame is produced. The quantity of acetylene used is about 10% more than oxygen. The equipment is very handy and has the added advantage that the same equipment, with a slight modification, may be used for cutting metal.

In the *Electric arc* process, a current, passing through a gap between the metal and the electrode, produces an electric arc of intense heat, in which a portion of the parent metal and the electrode are melted. Molten metal from the electrode is deposited on the parent metal with which it combines. This process requires an internal combustion engine, a generator, cable connections, and electrode holder; also coloured glass, shields and leather gloves for protecting the welder. Electrodes, which are manufactured of varying compositions to suit the varying qualities of the parent metal, are usually coated with a chemical or covered with suitable material (i) to protect the metal from atmospheric action, whilst passing through the arc, (ii) to obtain a more stable arc, and (iii) to obtain concentration in the arc stream. The normal length of electrodes is 16″ and the sizes mostly used for railway track work are Nos. 6, 8 and 10 S.W.G. The strength of the current depends on the size of the electrode and also on the thickness of the metal to be welded. The larger the diameter of the electrode, and the thicker the parent metal, the larger is the current. A current, larger than is necessary, burns the metal and produces porous welds. The currents required for various diameters of electrodes are approximately as follows :—

$\frac{1}{8}$″ diameter	.. .. ..	110 to 140	amps D.C.
$\frac{5}{32}$″ diameter	.. .. ..	140 to 180	,, ,,
$\frac{3}{16}$″ diameter	.. .. ..	180 to 230	,, ,,
$\frac{1}{4}$″ diameter	.. .. ..	240 to 350	,, ,,

Electric arc welding is extensively used for reconditioning points and crossings (*vide* para 820), the building up worn rails and for welding together two or more rails (*vide* para 219).

In the chemical *Thermit process*, the chemical combustion of aluminium and iron oxide produces the necessary heat as well as the filler metal.

2204. Estimating speed of a train

The speed of a train can be estimated by observing the time taken to cover a mile or part of a mile. In India, telegraph posts along the tracks are numbered and serve as excellent distance indicators. The numbers on each post give the mileage and the number of the post in that mile. There are usually 24, 18 or 12 telegraph posts to the mile.

A more convenient method of judging the speed, is to count the number of rail joints passed over in a fixed time. This does not need any observation of the telegraph posts and can therefore be used equally effectively at night.

The speed in miles per hour is the number of rail joints passed over in $x/1.47$ seconds, where x is the length of rail in feet, since 1 mile per hour equals 1.47 feet per second.

For 42′ long rails, the speed, in miles per hour, equals the number of rails or rail joints passed over in 42/1.47 namely 29 seconds. The corresponding figures for 36′, 30′ and 24′ rails are 24, 20 and 16 seconds.

2205. Safety of gangmen and of trains

Gangmen must be always on the alert for approaching trains and clear the track in good time. On sections with busy traffic or where the clear view is obstructed, a lookout man is posted and warns the men by blowing a whistle or by some other prearranged method.

When working on a double line, gangmen must stand clear of both tracks when a train approaches, as accidents have been known to happen when gangmen have moved to another track, to keep clear of a train, and have been run over there by another train.

Before any work, which is likely to obstruct the track, is commenced or when any danger is apprehended, or any obstruction found on the track, flags and detonators are fixed at specified distances from the obstruction to warn trains. Flagmen remain with the flags and stop trains. In some cases, it may only be necessary to slow down the train; this is also done by the flagmen. Unless there is an emergency, trains must not be stopped in mid-section. Work, which is likely to obstruct the track or impair its safety, should be timed to fit in the intervals between trains. When

trains need to be stopped or slowed down at night, as well as by day, temporary signals are erected and lighted at night. As an additional precaution, when trains have to be stopped at the obstruction, drivers are made to sign a book kept at the place of obstruction. The Transportation Department has to be advised in advance, to enable station masters to issue *caution* or *slow orders* to drivers of trains, and, if necessary, to enable the Control staff to regulate trains to avoid detention.

When a new line is built, it is inspected and passed by a Government Inspector of Railways, before it is opened for the public. The inspection includes investigation into the weight of rails, strength of bridges and structures, axle loads, standard dimensions, adequacy of engines and vehicles, rules for operation of the railway, and safety of the public. Sanction of the Government Inspector has also to be obtained in the following cases:—

1. Temporary or permanent diversions of the through line.
2. New bridges or new girders or extensions of existing bridges.
3. New signals or interlocking, or alterations to existing signals and interlocking.
4. Addition, or removal, of points and crossings in through lines.
5. Additional stations, additional ashpits, ashpans and examination pits on a through line.
6. Extensions or alterations to through lines.
7. Any regrading of through lines.
8. Remodelling station yards.

Certificates, to the effect that the work, being opened, is safe for the public are issued by the Engineer-in-charge in all the above cases. *Safety certificates* have also to be issued on reopening of a track after an accident or washaway, and also when raising the speed limit on affected lengths.

2206. Survey hints

(1) In order to obtain a line perpendicular to another line, without the use of a theodolite, equal distance XY and XZ (Fig. 2206*a*) are measured on either side of the point X, where the perpendicular is required. A measuring tape or chain, longer than YZ, is divided into two equal lengths and held as shown

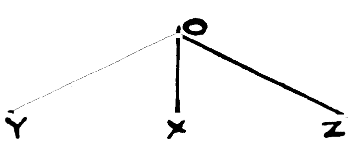


Fig. 2206*a*

in the figure. The point O at the centre of the tape or chain, when connected to X, gives the perpendicular.

(2) If the direction of the tangent OP (Fig. 2206*b*) is to be obtained at any point O on a curved track, Y and Z are marked off at equal distances from O and the centre X of the length YZ is also marked. The distance OX is measured and YP made perpendicular to XY and equal to OX. The line joining O to P gives the tangent.

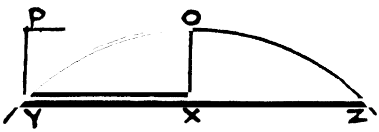


Fig. 2206*b*

(3) To obtain the angle between two lines AB and CD (Fig. 2206*c*), perpendiculars EF and GH from any two points F and H are marked and the lengths of these perpendiculars measured. The difference between these perpendiculars over the distance between the points F and H gives the tangent of the angle since

$$\tan O = \frac{GH-EF}{FH}$$

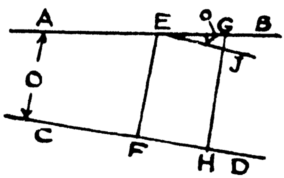


Fig. 2206*c*

(4) If any layout in a yard is to be altered or improved, the existing layout is surveyed and a drawing prepared. Alterations are shown on the same drawing. In order to make the survey and later to mark out the altered layout on the ground, one or more base lines are fixed, from which offsets are taken at short intervals, of say 10 feet, to all the tracks. The base lines may be fixed along the centre of any one track.

2207. Essentials of stores accounts

Persons in charge of the construction and maintenance of railway track are entrusted with large quantities of stores. Elaborate rules are framed by railways for their safe custody and accountal. A few essential points for their efficient maintenance are:—

1. All stores should be stored neatly and each item should be in its proper place.
2. Adequate precaution should be taken for their custody, small articles being stored in store rooms and large items

in enclosed yards. When stores have to be kept at the site of work, a watchman should be employed.

3. Stores should not be allowed to deteriorate. For instance, articles of steel should be painted and threads of bolts oiled.

4. All receipts and issues of stores must be noted down, daily, in a book. If this elementary precaution is taken considerable difficulties are avoided at a later date.

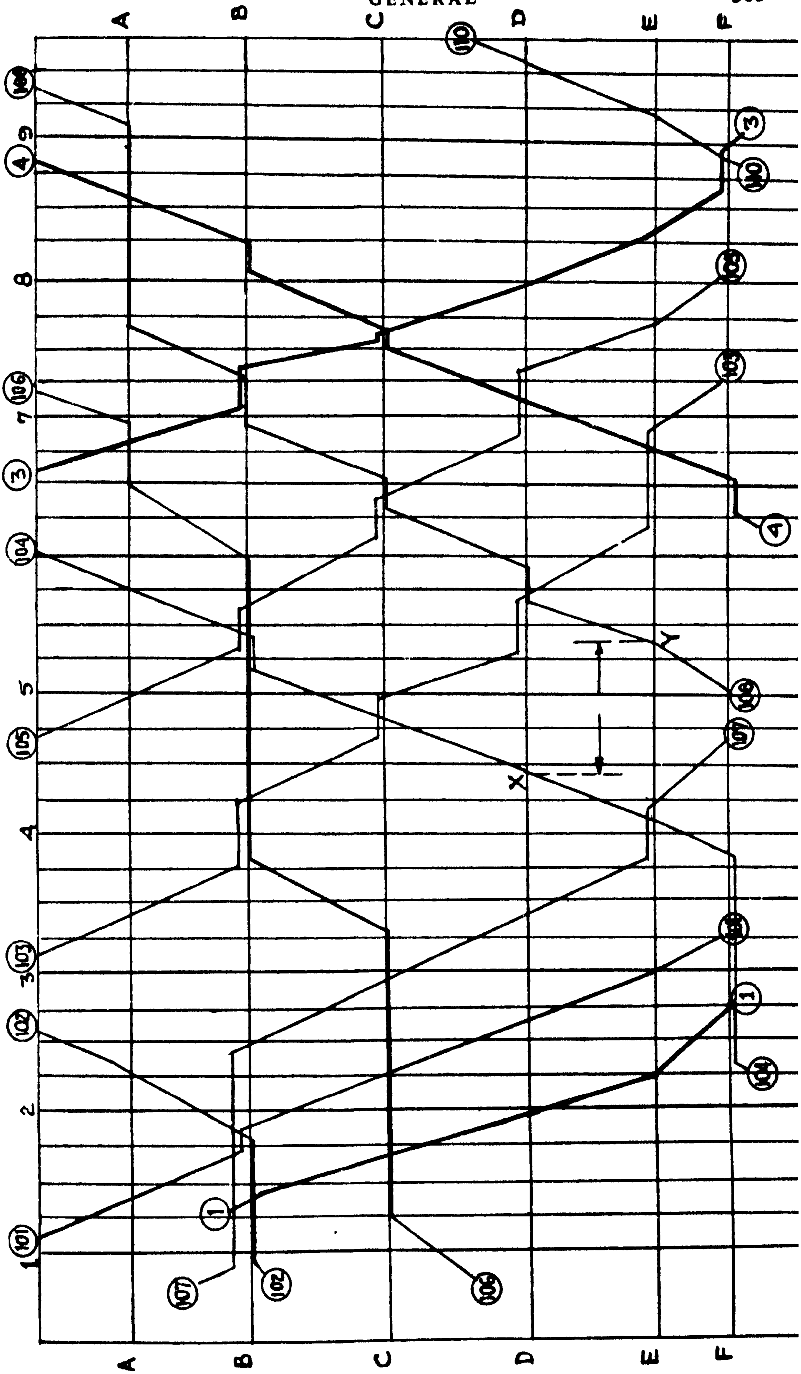
5. The balance of each item, as noted in the books, must be checked periodically with the "ground" balances.

2208. Control system of traffic working

In order to regulate traffic efficiently, most of the railways have centralised offices, known as *Control offices*, from which instructions regarding the movement of traffic are issued by means of a telephone system to stations. As the movements of all trains in the area, which an office controls, are reported to that office, the controllers are in a better position to regulate the traffic than the staff at individual stations, who are not aware of all train movements.

The control office also arranges distribution of empty wagons to various stations, makes provision for additional trains if required, and in some cases, is responsible for ordering trainmen on and off duty.

The *controllers* are equipped with earphones and have in front of them a board on which the layout of the various yards is shown for their guidance. Reports come in from each station by phone, as a train enters and moves out of the station. The controller records this, either on a chart or in a register. The chart, a sample of which is shown in Fig. 2208, may have the scheduled train timings or "paths" marked on it. The hours and quarter hours are indicated by vertical lines and the stations by horizontal lines. Each diagonal line indicates the movement of a train. The diagonals from left to right indicate trains from station A towards F, and diagonals from right to left, trains in the opposite direction. The short horizontal portions of these diagonal lines at stations indicate the duration of halt at the stations, either for the public or for servicing or for crossing trains from the opposite direction, or for allowing another train to pass in the same direction. For example, in the chart shown in Fig. 2208, train No. 1 does not stop at any of the stations shown. Train No. 106 stops at station C from


A
B
C
D
E
F
1
2
3
4
5
7
8
9
101
102
103
104
105
106
107
108
109
110
X
Y

1.15 to 3.20 to cross trains Nos. 1, 101 and 107. Train No. 103 crosses train No. 106 at station B, No. 104 at C, No. 108 at D and No. 4 at E.

The controller plots the actual timings, on this chart, as reported by stations. The chart shows at a glance whether a train is running to scheduled time and enables the controller to decide whether some important train running late, should not be allowed to overtake a less important train. These charts form automatic day-to-day records, which are very useful for analysing train working and effecting improvements.

At fixed times, each station reports the number of loaded and empty wagons at the station and its further requirements. When all these reports are collected, the controller is in a position to arrange, both the distribution of empty wagons with the least haulage and the despatch of loaded wagons to their destinations.

The above is a brief description of the method of control, common in India. There are several variations of this method and in some places, the control offices are made responsible for many other functions of train working.

The control of traffic from centralised offices leads to quicker working of trains and results in trains being more punctual. Goods trains are better loaded, the haulage of empty wagons is reduced and engines run longer mileages. In short, the capacity of the track is increased.

2209. Effect of engineering blocks and speed restrictions on traffic working

Permanent way men have to be in touch with the control office as blocking of tracks for repair work, restrictions of speed, movement of material lorries, etc. have to be arranged with the control office, so that trains do not suffer detention. An *engineering block* has to be so timed as to occupy an interval between the passage of trains. If, for example, a block was required at a place half-way between stations D and E (Fig. 2208), a block of 50 minutes would be available between 8.20 and 9.10 hours, namely between the arrival of train No. 3 at E and the departure of train No. 110 from E. If a block of longer duration is required in the morning, the trains cannot run to schedule. The above explanation indicates the necessity of reducing the duration of blocks to the minimum possible, of making out a detailed programme of work and of arranging the time of blocks in consultation with the Transportation Department. Engineering blocks have an adverse effect on operating

costs. The essentials for efficient execution of work, which necessitates blocking of the track and subsequent temporary speed restriction, are:—

1. Reduction of the block period to as short a time as possible.
2. Detailed planning of work.
3. Execution of as much preliminary work as possible before the block period.
4. Fixing of block period in consultation with the Transportation Department.
5. Removal of speed restrictions as soon as possible but consistent with safety.

The above remarks naturally do not apply in case of an emergency. It must also be remembered that, in all cases, safety of the travelling public is the first consideration.

Signalling and Interlocking

2301. General

THE object of Signalling and Interlocking is primarily to control and regulate the movement of trains, including shunting operations, safely and efficiently. Signalling also enables trains to be controlled in such a way that the greatest possible use is made of the existing tracks. Absence of signals would greatly impair the efficient working of a railway. Railway Signalling was first introduced in England in 1842 and in America in 1863. Interlocking was initially developed between 1856 and 1867. Track Circuiting was introduced several years later and Colour Light Signalling about 35 years ago.

Signalling, besides giving visual indication to the driver, to enable him to govern the movements of his train, covers the provisions for the safe passage of trains from one station to another.

Signals are invariably provided (1) for regulating the arrival and departure of trains from station yards, (2) for shunting operations, (3) at road crossings, (4) at points where a branch, or siding, meets the main track, and (5) at any other location where visual indication as to the situation ahead is necessary to be conveyed to engine drivers.

Control on movements of trains between stations is exercised in India by (1) the space interval method, such as the Absolute block and the Automatic block, (2) the time interval method, e.g. the "Following trains" system or (3) other systems, such as the "Pilot Guard" system.

Signalling may be divided into mechanical (including electro-mechanical) and electrical (including electro-pneumatic) signalling. If a mistake occurred at any time in the pulling of levers, by which switches are set or signals are manipulated, serious results would follow. In order to prevent such a possibility, the various levers are interconnected, either mechanically or electrically, and this interconnection is known as *interlocking*. Interlocking prevents setting of conflicting switches or signals. The trend of development in signalling and interlocking is to eliminate, as much as possible, the human element, in order to increase safety.

2302. Control of train movements

The safe movement of trains from one station to another is normally effected, in India, by what is known as the *Absolute block system*. By this system only one train at a time is permitted in a section. The track is divided into sections called *block sections*. A section is usually the distance between two stations. *Block Instruments* are installed in pairs at each station and each of the two instruments are electrically connected to corresponding instruments at the stations on either side. On a Single Line, the manipulation of the instruments under dual control, results in a token in the form of a Tablet, a Ball, or a Staff being released. This Token is handed over to the driver of a train as his authority to proceed to the next block section. As a check against human error, the instruments are so constructed, that only one token can be removed at a time from each pair of instruments. On a double line, the instruments do not contain tokens, but have indications in the form of minute semaphore signals or pointers, to indicate appropriate legends. The positions of these indications are under dual control and show whether the section ahead is clear, or reserved for a train, or actually occupied by a train. After per-

mission to despatch a train is obtained from the next station, with the help of block instruments, the station master, or his deputy, arranges for changing the aspect of the visual signals. The appropriate signal aspect, on double or multiple lines, and the possession of a token, in addition, on single lines, is the authority for the driver of a train, to proceed to the next block section. The station master at the receiving end adjusts visual signals, so that the train may enter his station.

On some branch lines, where traffic is light, block instruments are not used. Authority to despatch a train is obtained by the station master, from the station ahead, by telephone or telegraph and the driver is handed a written authority to proceed to the next station. In case of failure of block instruments, in the Absolute block system, similar written authorities are issued.

On some very busy sections in India, train movements are controlled by the *Automatic block system*, in which the human element is entirely eliminated. The signals are controlled electrically by the passage of trains over sections, by means of Track Circuits (para 2310). *Automatic Train control*, in which a train is automatically stopped if the signals are at danger, has not yet been adopted in India.

In the event of a complete breakdown of the telegraph and telephone systems, trains are allowed to proceed at fixed intervals on the *Following Trains system* on double lines. In case of failure of telegraph and telephone systems on a single line, the *Pilot Guard system* is introduced. This system is adopted also on double lines, if only one track is in use, due to an accident on the other track. In the Pilot guard system, a pilot proceeds by one train to the station ahead and returns by a train in the opposite direction. If more than one train is to proceed in the same direction, the pilot travels by the last train and personally hands the authority to proceed to the drivers of preceding trains.

2303. Types of signals

Visual signals in India are of three types, the semaphore, the disc and the colour light. A *semaphore signal* (Fig. 2303*a*) consists of a movable arm on a fixed post, the indication face being painted red, with a short white band, the opposite face being painted white with a black band. The movable arm can take up two positions. When it is in a horizontal or "on" position, it indicates "stop" or danger, and when lowered at an angle of 45° called the "off"

position, it indicates "proceed." The corresponding indications at night are, a red light for "stop" or "on," and a green light for "proceed" or "off."

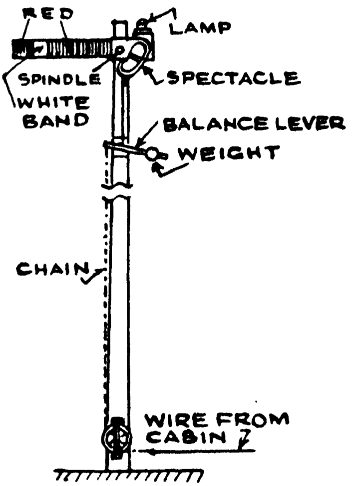


Fig. 2303*a*

The semaphore signal arms in some countries are moved in the upper, instead of the lower quadrant, and are exhibited in three positions and the signal is known as a three aspect upper quadrant signal. The arm may be moved to the upper quadrant through a position at 45° to the horizontal, indicating "caution," and finally to a position parallel to the signal post indicating "proceed." These upper quadrant three aspect signals are electrically operated. When the horizontal arm of a semaphore signal has a V-shaped notch at the free end, it is known as a *Warner signal.* In its horizontal or "on" position, it signifies that the signal beyond it is at danger. When the arm is at an angle of 45°, it indicates that the signal ahead is "off" and the driver may proceed at speed. On some railways in India, the Warner signal exhibits amber or yellow light, instead of a red light, at night, when "on," and in such cases, the Warner arms are also painted amber, or yellow.

Trains are not allowed to proceed beyond the position of the signal post, if the arm is horizontal. This, however, does not apply to the Warner signals, which may be passed in the horizontal or "on" position, as their function is simply to warn the driver, as to the position ahead.

Disc, or miniature semaphore signals (Fig. 2303*b*), are used for regulating shunting of vehicles in yards, and are known as *Shunt signals.* The disc is circular and is painted white, with a red band across it. When a disc signal has to indicate proceed, the disc is revolved and the red band assumes a diagonal position. The shape and movements of the miniature semaphore signals are similar to those of semaphore signals but the lights are smaller.

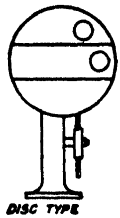


Fig. 2303b

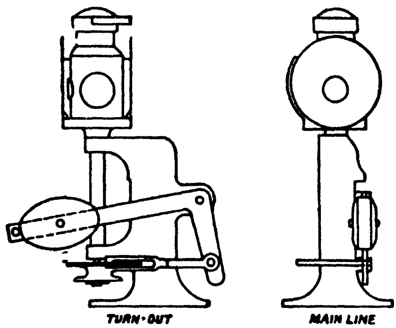


Fig. 2303c

Point Indicators (Fig. 2303*c*) are used to show the position of the switches. The Indicator is usually, but not always, in the form of an open box, white circular discs, 15″ dia. forming two opposite sides of the box and 5″ wide bands forming the remaining sides. The white discs indicate that the points are set for the main line. When the points are set for the turnout, the box is rotated on a vertical axis and the green bands take the place of the white discs. Night indications are a white light to indicate setting of points for the main line and a green light for the turnout. The indicator is actuated by the turning of the points. Indicators are not treated as signals.

The arms of principal semaphore signals are fixed to high posts, and if there are several arms to be exhibited, the arms are attached to small posts fixed on a gantry. Shunt signals and the disc type of point indicators are kept at a lower level, usually about a foot or two above rail level.

Colour light signals (Fig. 2303*d*) give indications by electric lights, both by day and night. Special lenses and hoods enable these lights to be seen distinctly in the brightest sunlight. They are used in India on urban and suburban sections with heavy traffic. They usually consist of three lights, fixed in a vertical row, on a post sufficiently high, to throw horizontal beams in line with the eyes of the drivers. The colour indications provided are, red for "stop", amber for "proceed cautiously" and green for "proceed." Colour light signals have several advantages over semaphore signals, particularly where a large number of signals are concentrated, as at heavily worked stations. Semaphore signals are lowered only when a train is due to approach and remain normally in the danger position. Automatic signals, however, normally

remain in the "off" or "proceed" position, unless a train is already in the section, when it automatically turns to "stop." Colour light signals are usually employed for automatic signalling.

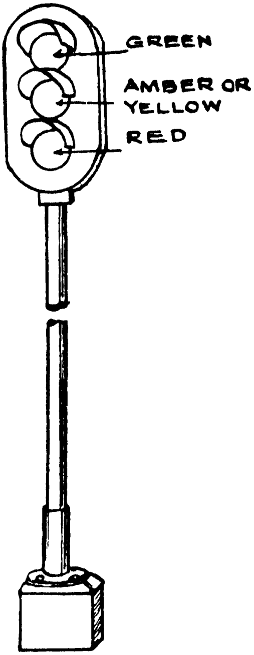


Fig. 2303*d*

There are four principal kinds of signals in use in India, namely the Warner, the Outer, the Home, and the Starter (Fig. 2303*b*). Other signals are the Calling-on, the Co-acting and the Shunt signals, which are classified as subsidiary signals.

The *Warner* Signal, which has a V notch at the free end of the arms, is often fixed on the same post as the Outer signal. The *Outer* signal is fixed at an adequate distance beyond the Home signal. The *Home* signal is provided at the farthest set of switches on the through line, and is a protecting signal. The *Starter* signal controls the movement of trains leaving a station and is normally fixed beyond the farthest point connection on the line concerned. *Advanced Starter* signals are often provided. A *Calling-on* signal, which is a small arm under the main signal arm, allows a train after it has been stopped by the main signal, to proceed cautiously beyond that signal. *Co-acting* signals are duplicates provided when the main signal is not visible from the requisite distance or is partially obstructed by structures.

2304. Mechanical signalling and interlocking

Switches may be turned over by levers, at site, connected to the pair of switches by a short length of rodding. They may also be turned over by a lever at a distance in a signal cabin. Signals are manipulated by levers, usually far from signals, and connected to the signals with wires. Signal and switch levers are normally grouped together in one or more frames, located at ground or platform levels or in an elevated structure known as a *signal box* or *cabin*. The grouping of levers at one or more points facilitates interlocking and results in economy, both in time and cost. The simplest method of interlocking which exists at many small stations in India, is based on the manipulation of key locks in one form or another. This type of interlocking is called *Indirect interlocking*.

In some cases, a double lock is fitted to a switch, from which only one key can be removed at a time. When the switches have been set for the correct route, on which a train is to be received, the released key A is taken to the appropriate signal lever which may be some distance from the points, and turned in a lock attached to the signal lever. This enables the appropriate signal to be lowered. If the switch is to be opened to permit shunting operations, key A has to be removed from the signal lever lock and this can only be done after the signal is put back to danger. Key A then opens the switch and releases another key B from the double lock. Key A in the meantime is back locked, namely securely held in its lock and cannot be removed, until key B is turned and locked. Key B, in turn, opens a second switch. Conflicting movements are rendered impossible by this method which is known as *Succession locking*. When there are several switches on a running line to be dealt with, the keys of all these point locks are placed in a *key box* in the station master's office. This key box can only be opened by a key, which when removed from a signal frame in which levers of a number of signals are located, prevents any signal from being lowered. When this box of siding keys is opened, the frame key is back locked and cannot be removed, until all the siding keys are put back in the box. This ensures that no signals are lowered whilst the switches are being manipulated for shunting operations. There are other methods of interlocking with the help of keys, but all of them involve considerable walks, from switch to signal levers, and from switch to switch, and consequent delays. They are, therefore, satisfactory only at stations where traffic is very light.

Mechanical interlocking not only provides safety, greater than that of Succession locking described above, but is more economical, as far fewer men are required. The main items of mechanical interlocking are (1) a locking frame, (2) switch fittings, (3) signal fittings, and (4) connecting devices from the locking frame to the switch and to signal fittings. The *locking frame* (Fig. 2304) consists of a number of levers, which work various switches and signals, fixed a few inches apart in a frame supported on a girder in a signal cabin. The pulling of a wire actuates a signal, whilst the manipulation of a rod operates a switch.

A latch rod, with a spring to hold it in position, and a handle for working it, is provided on each lever. The latch fits into one of the two notches in the quadrant, and holds the lever in position. The levers are usually painted in different colours for easy identification. The colours used are black, blue, red, green, yellow and white for points, point locks, stop signals, Warner signals, crossing

gate levers and spare levers, respectively.

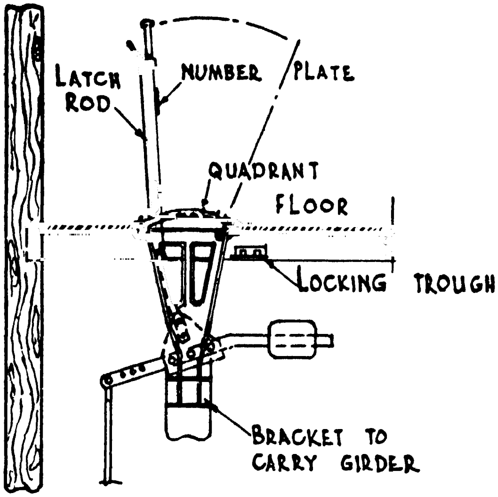


Fig. 2304

Interlocking of levers to prevent conflicting movements is carried out by means of *tappets* and *locks*. On some railways, double wire system of working is employed for both signals and switches. It entirely eliminates the use of heavier rods for working the switches and ensures the return of the arm to the "on" position, instead of relying on a balance weight at the signal post, to put the signal to danger by gravity.

2305. Switch fittings

Switch fittings consist of a connection from the rod leading to the lever frame, to the nearer of the two tongues. The connection is made through crank bars and stretcher bars, connecting the two tongues (*vide* Fig. 2305*a*). In order to ensure that each switch is in its correct position, a point lock is used and in order to further safeguard the turning of the switches, whilst vehicles are moving over it, a *lock bar* is installed. The point lock consists of a plunger, worked by a rod from the signal cabin, through the lock-bar, and moves in a plunger casing. Two stretcher blades, each with two slots, and attached to one switch each, also slide in the plunger casing and at right angles to the plunger. The plunger can only be driven home, when the slots in the stretcher blades register correctly, and once the plunger is in the slots, the switches cannot be moved.

The lock-bar consists of an angle or tee iron, of a length, a little greater than the longest wheel base of any vehicle used on the section, and is held to the inner face of one of the rails by short

revolving clips. When the point lock rod is worked from the signal cabin, the lock-bar is raised slightly above rail level and then lowered, due to the method of attachment on short revolving clips. If a vehicle happens to be over the lock-bar, the latter is prevented by the wheel flange from rising, and the point lock plunger, therefore, cannot be withdrawn.

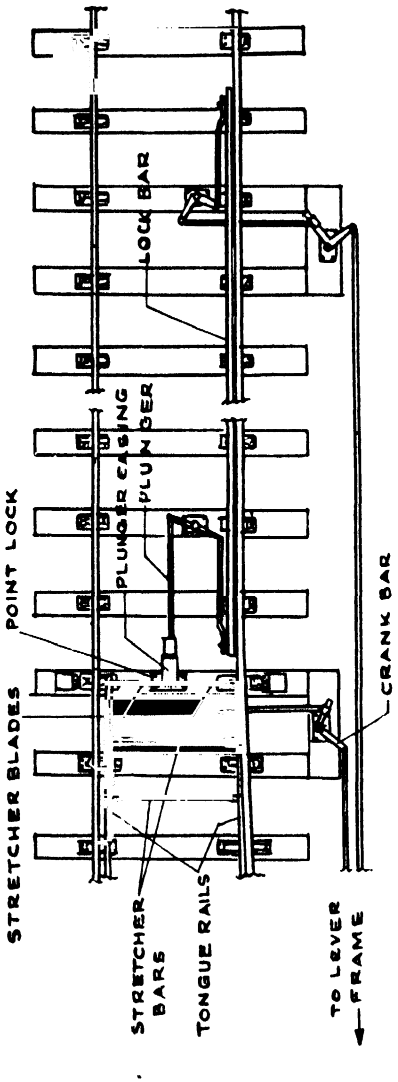


Fig. 2305*a*

In order to ensure that the correct signal corresponding with the position of the switches is lowered, a *Detector* is installed at the switches. Detector blades, connected independently to each of the two switches, pass through detector box A or B (Fig. 2305*b*). Signal wires from the cabin to signals are connected to blades, which also pass through the detector box, but at right angles to the switch blades. Appropriate slots, on both the detector blade and signal wire blades FG, guarantee the lowering of the correct signal.

Signal wire is saved if, instead of two separate wires from the cabin to the signals D and E, only one wire is used upto the switches. The manipulation of either signal is done through a *Selector*. The single wire C from the cabin is connected to a slide on which a pulley is fixed. A chain, threaded over the pulley, connects the

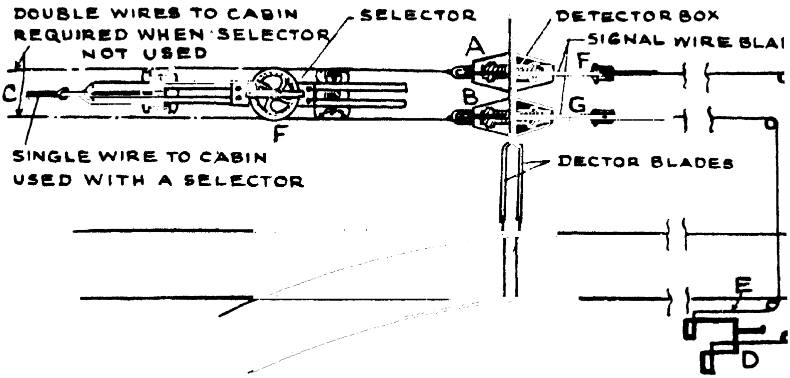


Fig. 2305*b*

blades attached to the signal wires. The position of the slot enables only one blade either F or G to move. When wire C is pulled, the slide with the wheel moves and if blade G is prevented from moving, the blade F is moved and the corresponding signal D is lowered.

2306. Signal fittings

The normal signal fittings (*vide* Fig. 2303*a*) consist of a signal arm with spectacles, joined to a balance lever with weight, through a connecting rod. The balance lever is also connected to the signal wire through a chain passing over a pulley at the signal base. A lamp is fixed on a bracket, so that it is behind one of the two glasses in the spectacle. The balance lever is installed to enable the signal arm to be returned to its normal position with its help. If by chance the wire is broken, the signal is returned automatically to the danger position. The spectacle, to which one red glass and one green glass are fitted, enables the correct light to be shown at night. A ladder is permanently fixed to the signal post for maintenance purposes and also to enable the lamp to be lit. When there are several signals on a gantry, a narrow landing is provided for the same purpose.

A signal may have to be controlled from two cabins, if the distance between the cabins is small. For instance, the starter signal of cabin X may have also to serve the purpose of the outer signal of cabin Y. The manipulation of such a combined signal is controlled from both cabins X and Y, by a device shown in Fig. 2306. Three levers, A, B and C are attached to the signal post as shown. Lever A is connected by wire to cabin X and lever B to cabin Y. Lever

C is fixed between and opposite to the levers A and B and is kept normally in the raised position with the help of a plate D This plate is attached to lever C and rests on the extensions of levers A and B. If both levers A and B are pulled, one from cabin X and the other from cabin Y, lever C has no support left, and due to its weight, it drops and lowers the signal If, however, lever A is pulled, but lever B is not pulled, the signal is not lowered as plate D is held by lever B and lever C is, therefore, prevented from dropping

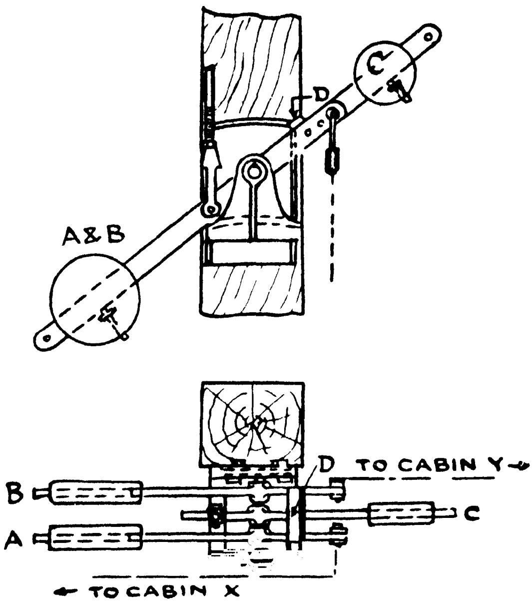


Fig 2306

2307. Connecting devices

The connection between a point lever in the signal cabin and the point, or switch, usually consists of a $1\frac{1}{4}$ pipe or solid rod A vertical rod is connected between the cranked end of the lever (*vide* Fig 2304), and a vertical crank at ground level A short piece of rod connects the vertical crank and a horizontal accommodating crank, or an adjustable deflecting crank, just outside the cabin (*vide* Fig 2307) Piping or rodding is then carried by the shortest possible route, on rollers fixed about 6 to 8′ apart, to concrete, cast iron or wooden bases Cranks are fixed at all changes of direction An adjustable crank is fixed opposite the switches Temperature variations, in long lengths of piping or rodding are automatically adjusted by *Compensators* (*vide* Fig 2307), which consist of a couple of cranks, either horizontal or vertical, with a connecting link between them

The connection to the signals consists usually of a 7-strand galvanised iron wire, each strand being of No 17 S W G It is con-

nected to the free end of the cabin lever and passes over vertical and horizontal wheels, to change its direction and is then carried by small pulleys, fixed to stakes, about 25′ to 30′ apart. The pulleys are of galvanised iron and are either of the swivelling or the non-swivelling type, the former being used for taking the wire round curves. The wire may be taken direct over a wheel at the foot of the signal post to the balance lever (*vide* Fig. 2303*a*), or it may pass through a detector (*vide* Fig. 2305*b*). In order to adjust the length of the wire periodically, adjusting screws are fixed at the cabin and signal ends. When the signals are at a great distance from the cabin, variations in length, due to daily changes in temperature, are adjusted by means of wire adjusters in the cabin.

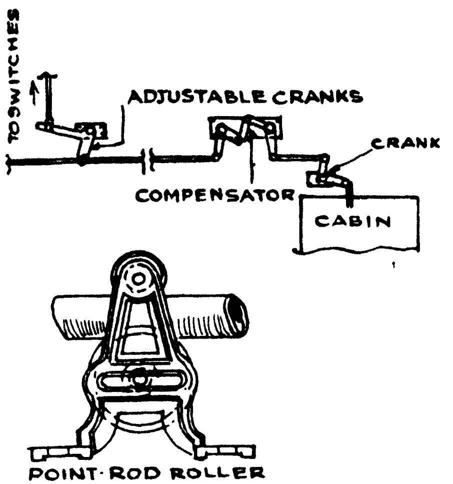


Fig. 2307

An economical system for the operation of signals as well as points from long distances is the *Double wire system*. In this system no piping or rodding is required and movements of signals and of points, etc. are carried out by two parallel wires worked together. Special fittings are required in this system at the points and at the cabin for interlocking.

2308. Method of interlocking and interlocking tables

The method of interlocking, with tappets and locks, is shown in Fig. 2308*a*. The *tappets*, which are lengths of steel about $1\frac{1}{2}'' \times \frac{5}{8}''$ in section, are attached either to the lever, or its latch rod, and have suitably shaped recesses in them. *Locks*, which consist of blocks of steel, of shapes to suit the recesses in the tappets, are provided in *locking troughs* and move at right angles to the tappets. Two or more locks are sometimes connected together with a *lock bar*. In Fig. 2303*a*, tappets 1, 3 and 4 have one notch each, and tappet 2 has two notches. There are five locks A, B, C, D and E in the locking trough. Lever 1 corresponding with tappet 1 can only be moved, when lock A is moved to the left of the position

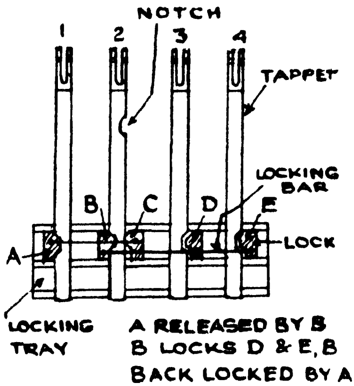


Fig. 2308*a*

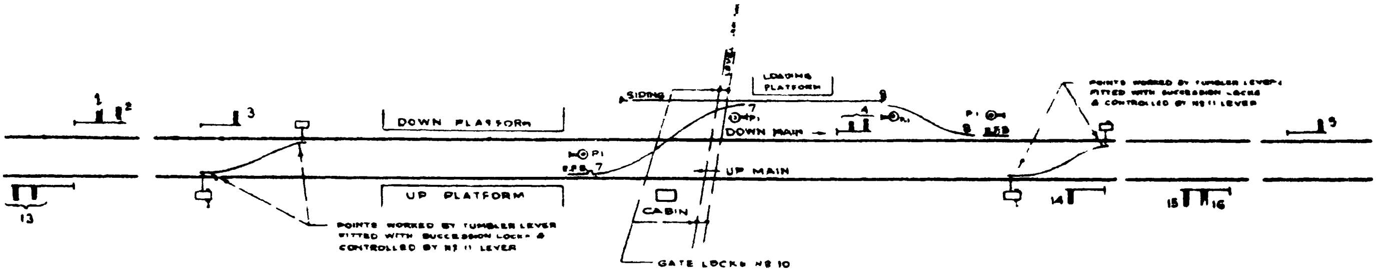
shown, as tappet 1 is held by lock A. Lock A is moved to the left, when the pulling of lever 2 moves tappet 2 so that the notch on the right hand side of tappet 2 is engaged by lock C. The movement of lock C to the left also moves lock A, as the two locks are connected with a bar. As tappet 1 is now free, lever 1 can now be pulled. The pulling of lever 1 prevents lock A from moving to the right and lever 2 is back locked, as tappet 2 cannot be moved due to lock C engaging its right hand notch.

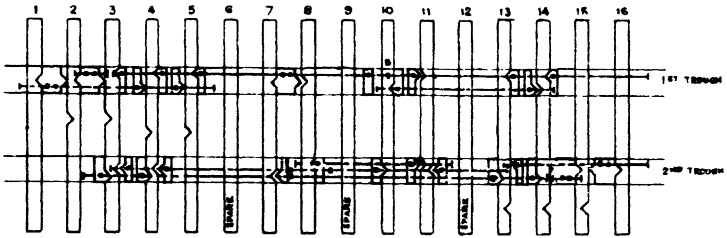
The movement of lever 2 shifts lock B also to the left and, as locks D and E are connected to lock B, levers 3 and 4 are locked by the pulling of lever 2. The above movements can be stated briefly as follows : Lever 1 is released by lever 2, levers 3 and 4 are locked by lever 2, and lever 2 is back locked by lever 1.

There are a number of types of lever frames and locking troughs, but the principles underlying their working are the same. Locking troughs are usually in a horizontal position below the lever frame, but vertical or inclined troughs are also in use.

Fig. 2308*b* shows switches and signals at a double line station. The description of the various levers in the cabin near the level crossing is given at the bottom left of the figure and a *locking table* is shown at the right centre. The figure at the left centre is a *locking diagram*, or *dog chart*, which shows the position of locks, lock bars and notches in the tappets, and also the shape of locks.

A locking diagram is prepared with the help of a locking table. The table indicates which levers are locked and which are released by the pulling of any particular lever. In preparing such a table, it must be remembered, that when lever A (Fig. 2308*a*) locks lever B, lever A is in turn locked by lever B. Also, that when levers are released, such released levers back lock the levers which have released them. Lowering of the home signal No. 3 in Fig. 2308*b* would indicate that the down line is clear for an adequate distance beyond this signal. It is obvious from the layout illustrated, that when signal No. 3 is lowered, (1) no vehicles should cross from the up line to the siding and *vice versa*, (2) no vehicle should move





DESCRIPTION OF LEVERS	
No 1	DOWN MAIN WARNER
No 2	DOWN MAIN OUTER
No 3	DOWN MAIN HOME
No 4	DOWN MAIN STARTER
No 5	DOWN MAIN ADVANCE STARTER
No 6	SPARE
No 7	CROSS-OVER SIDING TO UP MAIN
No 8	SIDING TO DOWN MAIN TRAP & TRAILING POINTS
No 9	SPARE
No 10	LEVEL CROSSING GATE LOCK
No 11	INTERLOCK FOR CROSS OVERS UP MAIN TO DOWN MAIN AT BOTH ENDS
No 12	SPARE
No 13	UP MAIN STARTER
No 14	UP MAIN HOME
No 15	UP MAIN OUTER
No 16	UP MAIN WARNER

No	RELEASES	LOCKS	BACK LOCKS
1			2 4 5
2	1.		3.
3	2	7 8 10 11	
4	1	7 8 10 11	
5	1.	8 11	
6	SPARE		
7		3 4 8 10 11 13.14	
8		3.4 5 7 10 11	
9	SPARE		
10		3 4 7 8 11 14	
11		3 4 5 7 8 10 13 14	
12	SPARE		
13	16	7 11	
14	15	7 10 11	
15	16		14
16			13 15

Fig. 2308*b*

from the siding to the down line and *vice versa,* (3) the level crossing gates should be locked, and (4) no vehicles should pass from the up to the down line over either of the two crossovers provided. In order to provide for these four contingencies, levers Nos. 7, 8, 10 and 11 (*vide* "Description of levers" in Fig. 2308*b*) must be locked by lever 2. This is shown in the third column of the locking table.

Again, taking into consideration the outer signal No. 2, it is obvious from the layout, that when this signal is lowered, it should not be possible to raise home signal No. 3. This is shown in the locking table in column 4 as lever 3 being back locked by lever 2. After lowering Outer signal No. 2 if the train is to run through the station, it should be possible to lower the Warner signal No. 1. This is indicated in column 2 as lever 2 releasing lever 1.

The locking table is completed by similar reasoning, each lever being dealt with in turn.

2309. Electrical and electro-pneumatic signalling and interlocking

Where a large number of switches and signals have to be operated from a mechanical frame, the working becomes very complicated, slow in operation and difficult to manipulate. In such cases, electric or electro-pneumatic power frames are used. In an electric power frame, all switches and signals are operated electrically. In the case of electro-pneumatic power frames, all switches are worked by compressed air, controlled by electricity, and the signals are operated either electrically or by compressed air.

2310. Track circuits and automatic signalling

A Track Circuit is a method of using the running rails of a given section of the line, to form part of an electric circuit for indicating to the signalman in the cabin, the presence of a train on that particular section, and to lock signal levers where necessary. The track is divided into lengths AB, BC, etc. (*vide* Fig. 2310)

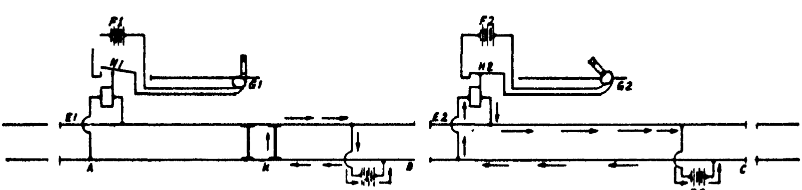


Fig. 2310

which are electrically insulated from one another. A small current is passed through each section AB, BC by means of batteries D_1, D_2. This current is passed through electric apparatus known as *track relays*, E_1, E_2; F_1, F_2 are other batteries, a current from each of which manipulates signals G_1, G_2. When a current flows through the track relay E_2 it closes a contact H_2. This completes the electric circuit from battery F_2 to a motor on the signal G_2 by which the signal is lowered. If a vehicle or train K happens to move across section AB, the current from the track battery D_1, instead of passing through the track relay E_1 passes through the wheels and axles K, as these provide an easier path for the current. As there is no current to energise the track relay E_1, contact H_1 opens. This opening breaks the flow of current from signal battery F_1 to the signal motor G_1 and thus places the signal G_1 in the danger position.

Besides contacts H_1 and H_2 of the track relays which are utilised for operating signals, there are other contacts also provided on the relay to work electric locks on levers and other local circuits in interlocking frames.

The presence of a train or a vehicle on the track therefore automatically controls the signals or levers and eliminates human error.

Track circuits may be operated by making use of both rails or one rail only, and the current supplied may be either a direct current through batteries, or an alternating current through transmission lines. In the case of electric traction, where the track rails are used for the return of the traction current, alternating current is used for track circuits and both the traction current (direct current) as well as the track circuit current (alternating current) pass through the same rails. In order to provide a continuous path for the traction return current and at the same time insulate the track circuits from one another, the rails are insulated, as already explained, and *Impedance bonds*, which give the required path to the traction current, are provided at the insulated joints.

As both rails must remain electrically insulated from each other for track circuits, wooden sleepers, which are not good conductors of electricity, are normally used in the track, but other types of sleepers can also be used provided they are suitably insulated from the rails.

The rail joints at A, B, C (*vide* Fig. 2310) have to be insulated to prevent current from one circuit passing to another. The intermediate rail joints, on the other hand, have to be electrically

bonded by means of copper or galvanised iron wire, attached to the adjoining rails, to provide an easy path for the track circuit current, which is very small.

In automatic signalling, the human element is eliminated from the control of train movements. The working of automatic signals depends essentially on track circuits and the system is based on the provision of an adequate space interval between trains. Some of the advantages of automatic signalling are : increased safety, reduction in delays to trains and increase in track capacity. For these reasons, automatic signalling is usually found in heavily worked lines in and near large cities. As electric traction is introduced to deal with heavy traffic with the greatest despatch, automatic signalling is often associated with electric traction. Automatic signals are usually of the colour light type, as electricity is available and such signals are very much simpler to operate. When the semaphore type of signals are used with automatic signalling, the signal arms are pointed.

Automatic signalling may be employed on single, double, or multiple tracks. The working on double tracks, when trains move in one direction only on each track, is simpler than for single tracks, where signalling both of following and opposing trains, has to be catered for. In either case, a certain overlap is provided between the track circuits and the signals, the length of the overlap being governed by the distance necessary to stop a train at full speed.

As will be realised from Fig. 2310, the normal position of an automatic signal is the clear or 'off' position, as opposed to the normal danger position of mechanically operated signals. Only when a train or vehicle is on the section, does the signal show danger. It is not essential for automatic signals to be of the normal clear type; the normal danger type of automatic signals also exist in some countries.

2311. Automatic train control

The object of automatic train control is to help the engine driver to observe visual signals and in case of his failure to do so, to prevent possibilities of an accident.

Automatic train control is achieved through various devices which help the engine driver to observe visual signals and, in case of his failure to do so, to automatically reduce speed and bring the train to a stop. These devices may be broadly divided into two groups, namely, cab signalling and automatic stopping devices.

In cab signalling a variable electric current passing through the running rail is picked up by the locomotive and translated into colour light signals in the cab of the locomotive.

There are variations in this system, a warning siren also being sounded in some cases in the locomotive. In other cases automatic control of speed is also provided for. Where speed recording graphs are installed on locomotives, the signal indications are also automatically recorded and the response of the driver through the pressing of a vigilance button is likewise indicated on the graph.

In the second method, train control is effected by mechanical or electrical devices which either bring the train to a stop automatically if the signals are not observed by the driver or reduce its speed and, subsequently if the driver fails to respond in a specified time, bring the train to a stop.

The device in all cases consists of two parts, one part being installed in the track and the other in the locomotive.

In the mechanical trip type, a movable trip is fixed to the track which is raised when the train is to be stopped. A corresponding contact piece on the locomotive when it comes in contact with the trip in the track, automatically puts on the brakes and brings the train to a stop.

In another device, a long angle iron or "ramp" is fixed parallel to and outside the track. A "shoe" is attached to the locomotive and the lifting of this "shoe" above its normal position automatically applies the brakes. The "shoe" is lifted above its normal level when it passes over the "ramp." When a train is not to be stopped, namely, when the signals are in the "off" position, an electric current is passed through the "ramp." The "shoe" picks up this current which prevents the application of the brakes, even though the "shoe" is lifted above its normal position.

In yet another system, the signals are transmitted by induction, and the need for physical contact between the apparatus in the track and that in the locomotive is eliminated. When a distant signal is passed at caution, or a starting signal at danger, a whistle is sounded through induction in the cab. If the driver does not respond by pressing a vigilance button, brakes are automatically applied and the train brought to a stop.

Cab signalling is common in America and France, automatic records also being obtained on speed recording graphs in the latter country.

American legislation provides for the installation of automatic train control on all tracks where speeds above 80 miles per hour obtain.

Automatic stopping devices of various types exist in Britain, Germany, U.S.S.R., and other European countries.

Automatic train control of the stopping device variety with the trip, ramp as well as induction type have been tried out in India.

2312. Centralised train control

In para 2208, the working of Control Offices has been explained. Instructions are issued by the Control Office through phones to various station masters and the control on movements of trains between stations is exercised by the station masters, *vide* para 2201.

In centralised train control, train movements are directed by signals only, which are controlled over a considerable mileage of track from a control room. Such centralised control has been made possible through the provision of interlocking between switches and signals in the field instead of at the levers in cabins. The movements of trains are controlled by different aspects of the signals which are interlocked with the switches and are operated from the central control room.

The greatest advantages of this system are that considerable savings in time of train movement are effected and the line capacity of a single track is increased to such an extent that it can handle the traffic normally requiring a double track and the necessity of doubling the track can be avoided.

The introduction of C.T.C. on a double track further increases traffic capacity. C.T.C. can also handle traffic satisfactorily during peak periods. One of the chief reasons for this lies in the fact that goods and other slow trains lose considerable time waiting in sidings for faster trains to pass them as such passing cannot be timed closely by the Line clear system. With C.T.C. the detention period is reduced to a minimum as the movement of all trains is traced on an illuminated diagram in the C.T.C. room and closer timing for passing of trains can be achieved due to the exact position of each train being known. A further speeding up of train movements is achieved by installing flat turnouts enabling trains to negotiate them without considerable reduction in speed and introducing loops about four times the length of a train so that the train being by-passed need not be brought to a halt.

The savings in time of train movements are so substantial that a four-line track in U.S.A. has been converted to a two-line track, each track being worked as a single line with movements of trains in either direction. Considerable economies are effected through reduced track and signal maintenance, and quicker movement of trains without reduction in track capacity.

In order to enable trains to run in either direction on both tracks, crossovers are installed at suitable intervals of, say, about 5 to 10 miles and the trains diverted from one track to another, as required, through power-operated switches and signals. The flexibility of this arrangement is so great that no loops for by-passing a train are necessary. Long curved switches are used which enable the trains to negotiate a crossover at high speeds of over 50 miles per hour.

2313. Standards of signalling and interlocking

Certain standards are laid down for all railways in India, as regards the minimum requirements of Signalling and Interlocking. Three standards are specified. Standard I is used where the speed through stations is limited to 30 miles per hour; standard II where the speed through stations is upto 45 miles per hour and standard III for unrestricted speed.

In case of standards II and III, trains are not allowed to run through a station, unless the through line or lines are isolated from all other lines by the switches being set and interlocked in such a way that no vehicles can come on to the through line when signals are lowered for a through train. Even for standard I signalling, isolation is recommended and the cessation of all shunting operations is enforced. Vehicles which are not attached to engines, are not allowed to stand on any unisolated track.

Direct interlocking between switches and signals is compulsory for standard III and optional for standard II signalling. Indirect interlocking by means of key locks is essential for standards I and II. The operation of signals in standard II signalling is under the direct control of the station master, who locks up the signal frame.

The provision of signals becomes more elaborate with the rise in the standards.

Bridge Maintenance

2401. General

BRIDGES and culverts are an important part of railway assets, and it has been computed in America that they represent about 10% of the total investment. Annual maintenance costs have been worked out as 1½ per cent of the total cost of maintaining a railway. Structures spanning gaps of 6 feet and less may be termed *culverts* and those with larger spans may be called *bridges.* When the span of a bridge is 40 feet or more, or when the total of a number of smaller spans of a bridge comes to over 60 feet, such bridges are termed *major bridges.* Bridges and culverts not only require constant and careful maintenance, but have to be strengthened or rebuilt from time to time.

2402. Types of bridges and culverts

Railway bridges and culverts may be broadly divided into (1) pipes, (2) rail openings, (3) flat top or box culverts, (4) arches, (5) reinforced concrete slab culverts, and (6) girder bridges both steel and prestressed concrete.

Pipes are usually of plain or reinforced concrete, or of corrugated iron. If very small openings are required, cast iron pipes are sometimes used when there is insufficient earth cushion between the pipe and the track. It is unusual to find pipes of over 3 feet diameter under the track.

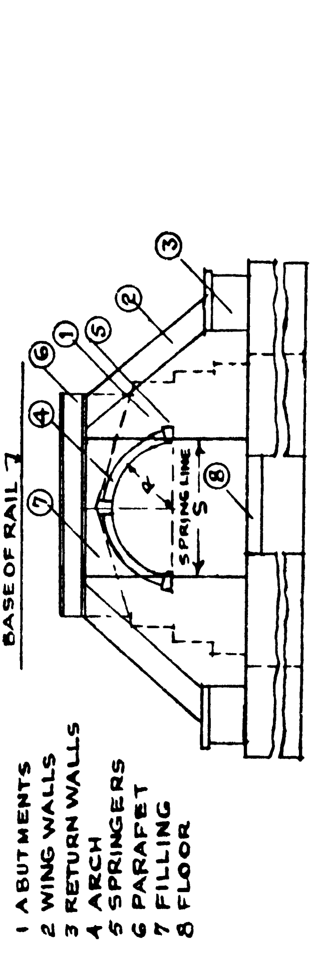


Fig. 2402a

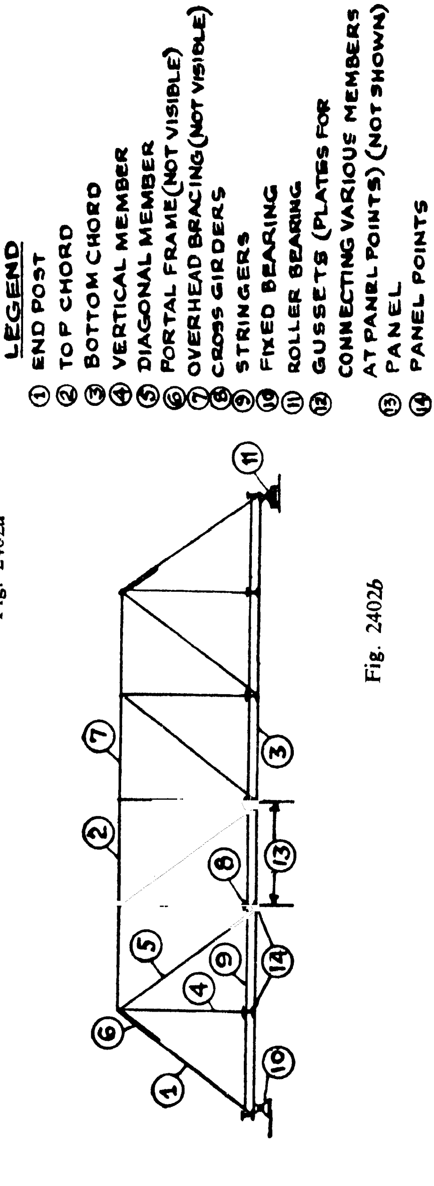


Fig. 2402b

Rail openings are small openings provided in shallow banks, where other types of openings would not give sufficient waterway due to the restricted height. They are a miniature type of girders and the spans do not normally exceed 3 feet.

Flat top or *box culverts* are in the shape of rectangular boxes with slabs of stone or concrete. These are also meant for short spans only.

Although *arches* may be constructed of any reasonable span, such spans do not normally exceed 30 feet.

Reinforced concrete *beam and slab bridges* are used for spans of size about that of arches.

Steel girder bridges are divisible into two main categories, namely *plate girders*, for spans normally up to 100 feet and *open web*, or *lattice girders* for larger spans. Girders are invariably used in pairs, although more than two girders per span may sometimes be found. In the *deck type* girders, the track is laid on the top of girders, whilst in a *through type* the track is carried betweeen the two girders.

The *superstructure* of a bridge is the portion which spans the gap and sustains the load. The *substructure* supports the superstructure and transfers the load to the underlying soil. In a girder bridge, the superstructure consists of the girders and the substructure of the piers and abutments. Figures 2402*a* and 2402*b* illustrate various parts of an arch bridge and an open web steel girder respectively.

Foundations of bridges may be of several kinds, such as mass foundations, wells, caissons, piles, etc.

2403. Inspection and maintenance

Bridges and culverts are subjected to considerable wear by the passage of trains over them and by forces of nature, such as floods, corrosion of steelwork, and decay of timber. In order to maintain them in an efficient condition, they have to be periodically inspected and repaired. The inspection is carried out by Track Inspectors, Bridge Inspectors and Engineers. Usually, Track Inspectors inspect all culverts and smaller bridges and Bridge Inspectors are responsible for a detailed inspection of major bridges and particularly the girders. Engineers make detailed inspection of all bridges once or twice a year. The results of their inspection are entered in special registers, so that a complete record from year to year is available for each bridge. The inspection must be

thorough and systematic. A casual look over the bridge is not only useless but dangerous, as some serious defect might be overlooked. Immediately after the inspection, steps are taken to carry out necessary repairs. The best time for inspection, in India, is at the close of the monsoon, when damage, if any, caused by floods can be ascertained and again, before the beginning of the monsoon when all repairs carried out since the previous monsoon may be checked. It is very important that minor defects should not be neglected as these increase, often rapidly and necessitate heavy expenditure. If the repairs carried out are subsequently found to be ineffective, the same method of repairs must not be repeated but a different method employed. For instance, it is perfectly useless to cement point a crack which opens out year after year. Pressure grouting, fixing of cramps or other methods should be adopted. Repairs must be carried out systematically and to a programme. Unless this is done, the work will not be completed before the next monsoon as the number of bridges and culverts in each section is large.

2404. Maintenance of foundations and protection works

Foundations are liable to scour during floods. The stability of the bridge may be affected due to this and the substructure may be damaged. In case of small streams, the quantity of water is reduced considerably after the monsoon, the stream in many cases drying up altogether, and no difficulty presents itself in detecting the scours. In large rivers, where the water flows throughout the year, soundings have to be taken. Scours occur not only adjacent to piers and abutments but also along protection works. Protection works usually consists of earth bunds, reinforced with pitching, which confine the flow of water through the bridge during floods and prevent damage to the bridge approaches. Scours are invariably filled with heavy rubble. If scour has damaged the floor, which is provided in some culverts and small bridges, the floor has also to be repaired. Mass concrete on top of rubble is an effective method of repairing scours in floors. The bunds and the foot of the slopes of approach banks are often provided with stone pitching. The pitching consists of rough stones, set together, and prevents currents of water washing away the earth of the bunds or banks. With rivers or streams, which have strong currents during floods, it is advisable to cement grout the pitching, as once the pitching is scoured at the bottom of the slope the whole pitching is gradually destroyed. This does not happen with grouted pitching, even if its lower portion is damaged.

If it is found that the floor of a culvert or bridge is badly scoured, a floor is put in. In such cases, *drop walls* are necessary. Drop walls are built across the stream from one abutment to the other or from return wall to return wall and with its top level just below the river bed. Drop walls are built on the downstream side or on both the up and downstream sides. Scour sometimes takes place beyond the downstream drop wall. Rubble is filled in such scours and, if the scour persists, rubble pitching on top of the rubble filling, helps. This pitching is sloped down from the drop wall. If the bunds and bridge approaches are made of soil which does not consolidate but remains loose, the surface, where there is no pitching, must be turfed. This prevents the earth from being washed away in heavy rain. The best way of turfing is to dig up clods of turf from the surrounding land and lay it on the slope. If this is done at the beginning of the rains, a prolific growth results. Slopes of banks and cuttings, which erode rapidly, can also be improved by turfing.

2405. Maintenance of substructure

Cracks are sometimes found in piers and abutments. If they are very few, or superficial, or so located that they do not affect the strength of the structure, they are pointed with cement mortar. It must be remembered that unless material, such as mortar or concrete, of which cement is an ingredient is kept moist for a number of days, the strength of the material is considerably reduced. Pointing, plaster, masonry or concrete repairs, unless sprinkled with water regularly for the required period, have very little strength.

For cracks, which are wide, or in an undesirable place, pressure grouting may be done. The more elaborate work may be carried out with a grouting machine in which cement mortar is injected under heavy air pressure into the cracks and penetrates the full depth of the crack. A simple method of grouting under pressure is to fix a length of half or three-quarter inch diameter pipe in a hole made in the crack and pour cement grout through a funnel on the top of the pipe. If any portion of the masonry is badly cracked, it is best to remove and rebuild that portion.

Cracks are often found in bed blocks, on which girders rest or below the bed blocks starting from the lower corners. The cracks are due to insufficient or non-uniform distribution of girder loads. If the cracks are numerous, the best procedure is to replace each pair of bed blocks with a long reinforced concrete block supporting both girders.

Abutments are sometimes found to lean forward. One of the common causes of this is the expansion, with moisture, of expansive soil filling behind the abutment. It is therefore usual to fill good selected material behind new abutments. Abutments, which are leaning forward, must be strutted with reinforced concrete or other struts, or they may have to be rebuilt. If the abutment leans forward only very slightly and if there is no subsequent increase in the angle, the abutment may not be unsafe.

2406. Maintenance of superstructure

Cracks are sometimes found in arches. These are either parallel to the track or at right angles to the track. Parallel cracks are not serious, but cracks at right angles to the track may affect the stability of the arch. If the crack is only a fine or hair crack, it should be pointed and inspected at short intervals. If the crack is wide, the arch should be temporarily supported with a sleeper crib or the crack should be pressure grouted. If the arch is found weak, the arch may be rebuilt or a relieving girder introduced on top of the arch. In the latter case, the arch does not carry any load.

A certain amount of earth cushion is necessary on top of arches or box culvert slabs. A 3-feet depth of cushion is considered adequate. Cracks may occur, if this depth is insufficient.

Ballast walls, which retain the earth and ballast beyond the ends of girders, sometimes bulge on account of the horizontal thrust behind them. The present practice is to replace damaged masonry ballast walls with walls of precast reinforced concrete sections. *Run-off frames* (*vide* para 1202) help to diminish the thrust on the ballast walls.

Girders are fixed to bed blocks at one end only. The other end is allowed to move longitudinally to permit expansion and contraction of the girders. For small spans, sliding plates are used at the free end, and for larger spans, a nest of rollers is necessary. The sliding ends must be greased periodically, say once a year, if they are to function satisfactorily. Jammed ends are liable to produce cracks in the abutments or piers.

Smoke from locomotives has a deteriorating action on reinforced concrete, resulting in cracks and exposure of reinforcement. The most effective remedy is to apply cement mortar by shooting it from a nozzle under air pressure. Prevention consists of interposing metal or other sheeting to prevent the smoke coming in contact with the reinforced concrete.

If creep is heavy, the approaches to bridges must be heavily anchored. Anchoring on the bridge itself is to be avoided. Usually, on large bridges, special expansion joints in rails are provided, one per span, and all the intermediate joints are welded.

Girders, for very short spans, are sometimes not fixed to the bed block at one end. Such girders are found to creep and butt against one of the ballast walls. This damages the ballast wall and reduces the bearing of the girder at the other end. The remedy lies in fixing the girder at one end with holding down bolts.

Decks of girder bridges are of two kinds:—

(*a*) Covered deck with the track laid on a normal layer of ballast.

(*b*) Open deck with track sleepers resting directly on girders.

Maintenance requirements of track fittings on open deck bridges have been explained in paras 509, 510 and 1202.

In case of covered deck bridges, the decking consists of steel troughs or concrete slabs fixed to the girders.

The latest method is to fix the rails direct to the girders or to concrete slabs. This avoids the use of sleepers and saves head room. Maintenance is also reduced.

Rivets of girders are sometimes found to work loose. The method of finding out loose rivets is to hold the head of a rivet between the thumb and first finger of the left hand and to tap the same head with a light hammer. Any looseness is felt by the left hand and the rivets are suitably marked for renewal. It is not necessary to renew rivets which are only slightly loose. Rust stains, emanating from under the rivet head, are a sure indication that the rivet needs replacement. The loose rivet must not be cut out with a chisel and hammer but should be drilled out, otherwise the adjoining rivets are likely to be loosened. Pneumatic drills and riveting tools are desirable for this work.

2407. Painting of girders

The largest maintenance item of steel girders is painting for prevention of corrosion. On some large bridges, near sea coasts, where corrosion is very heavy and painting has to be done at short periods, a permanent gang is maintained. Corrosion is primarily due to contact of steel with water, or moist air, and is aggravated by the presence of acids.

The paint found most suitable and economical in India is red lead mixed with linseed oil. This is the standard paint for bridges. One or two coats of this paint are applied and a final coat of red oxide in linseed oil is given. Where corrosion is heavy, bitumen paints are used with success.

Protection against corrosion adopted on most railways of the world consist mainly of lead paints, particularly red lead. Aluminium, zinc and bitumastic paints are also used whilst galvanisation is sometimes adopted.

The paint on steelwork should be renewed before the existing paint film is broken, blistered, or has peeled. It is false economy to postpone painting as by doing so the "life" of steelwork is shortened. If it is not possible to completely repaint all the girders, which show signs of deterioration of paint, patch painting should be done. This must, however, be considered only a temporary measure. Corrosion invariably starts at rivet heads and at junctions of the various members of the girders. An extra coat of paint may be applied at these places before the general painting is started.

Before painting is done, the steel surface must be thoroughly cleaned. It is not enough to remove blisters and loose paint only, but every particle of paint must be removed. The removal of old paint is done with scrapers and wire brushes, and is a slow process. Flame cleaning or sand blasting is also adopted for paint removal. Before the first coat of paint is applied, the cleaned surface must be inspected, but no time should, on account of inspection be lost between the cleaning and the application of the first coat. The surface must also be thoroughly dry and painting of bridges should, therefore, not be done in the monsoon.

In order to ensure the proper application of each coat of paint, the colour of each coat should vary. This can be easily done by adding small, but different, quantities of black pigment to the second and third coats. Each coat must be thoroughly dry before the next coat is applied. The paint must be thoroughly ground in portable paint mills.

Paint may be applied with bristle brushes, which may be flat or round. If they are flat, they should not be more than 4 inches wide. In order to preserve the bristles the upper portion of the bristles should be tied with twine or metal. This binding should be removed when the brushes are worn. The brushes must be washed in kerosene, after use, to prevent caking. Spray painting is a rapid and effective method of painting.

2408. Strengthening of steel bridges

The life of a steel bridge is considered to vary from 50 to 75 years and even 100 years whilst that of a reinforced or prestressed concrete bridge is reckoned as 75 to 100 and possibly 120 years. (In America the life of a R.C. or P.C. bridge has been considered as little as 40 years.)

Renewal or strengthening of bridges which are still serviceable is invariably necessitated on account of higher speeds or increased loads.

Methods adopted for strengthening steel bridges are:—

(1) Provision of intermediate piers to halve the span.

(2) Increasing the member of cross girders.

(3) Duplication of main girders.

(4) Addition of plates or other sections to strengthen individual members of the girders.

(5) Increasing web depths of main girders.

(6) Addition of reinforcing trusses either above or below the main girders.

2409. Repairs to bridges

When heavy repairs, or partial rebuilding of bridges, have to be carried out, the track has to be supported on temporary supports to pass trains. Alternatively, the track may be diverted temporarily (*vide* para 1603). For temporary supports, *sleeper cribs* (para 1606) and *service girders* (para 1608) are invariably used. If a new foundation is to be built, the span of the service girders

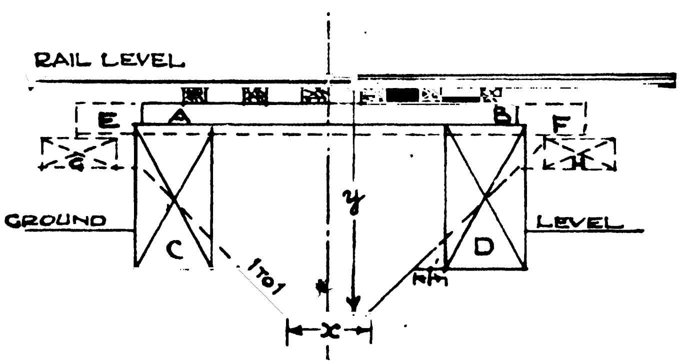


Fig. 2409

and the depth, to which sleeper cribs are to be taken, is decided by the width and depth of excavation. In Fig. 2409, if y is the depth of excavation and x its width, and girders of length AB are available, deep cribs C and D are necessary. The distance apart of C and D is decided by the length of girder AB. The depth of these cribs is governed by the width of the excavation. Usually a 1 to 1 slope is allowed in the excavation and the cribs are built about one foot from the edge of the excavation. With longer girders EF, shown dotted, cribs G and H of shorter depths are sufficient. The procedure for installing and removing the cribs and service girders is similar to that described in para 1605.

2410. Bridge repair tackle

Fibre ropes are made of cotton, hemp, manila, jute, etc. Jute rope is not strong enough; cotton and hemp ropes are expensive and manila rope is most commonly used.

The safe load in cwts., for manila ropes, is taken as the square of the circumference in inches. Thus a rope 2 inches in circumference can lift 4 cwts. and a 3" rope can take 9 cwts. As these figures give a factor of safety of over 6, the loads may be safely increased by 50% on new ropes.

Wire ropes are made of a number of strands, usually six, of steel wires and each strand is composed of a large number of wires, usually 19 or 27.

Wire ropes can safely take 9 times the load which a manila rope of the same circumference can take, namely, safe load in cwts. $= 9C^2$ where C = circumference in inches. A wire rope of 1" circumference can take 9 cwts. load, a $1\frac{1}{2}$" wire rope can lift $20\frac{1}{4}$ cwts. or, say, 1 ton, and so on. These figures give a factor of safety of over 6 and if the wire ropes are carefully used and have not been kinked, double this load may be permitted.

Fig. 2410a

Pulley blocks (Fig. 2410*a*) consist of one or more sheaves, suitably held together. By using a combination of blocks, the effort required and the load on the rope is reduced by the number of times the rope is reeved through these blocks. A rope of smaller capacity can therefore be used if pulley blocks are employed. The blocks in most common use are two-sheave and three-sheave blocks. The blocks are used in pairs, one block having a sheave less than the other block.

Chains: The strength of a chain depends on the diameter of the metal forming the links and the load, in tons, which a chain can bear, may be taken as $6d^2$ where d is the diameter of the metal of each link. Thus a chain, with links made of $\frac{1}{2}''$ diameter metal can lift $1\frac{1}{2}$ tons.

Winches which may be defined as cranes without jibs, are used for hoisting loads with ropes and blocks. A winch consists of a drum (Fig. 2410*b*), rotated by handles, through gear wheels. The winch is fixed on the ground and held in position with wire ropes attached to an anchor. The anchor may consist of any heavy material, buried in the ground, at a sufficient depth to prevent it being pulled out by the forces exerted on the winch. A brake is attached to the drum and is used for regulating the speed at which a load is lowered. The rope winds round the drum as the handles are turned and the load is lifted or pulled. A useful size for a winch is one of 5 ton capacity.

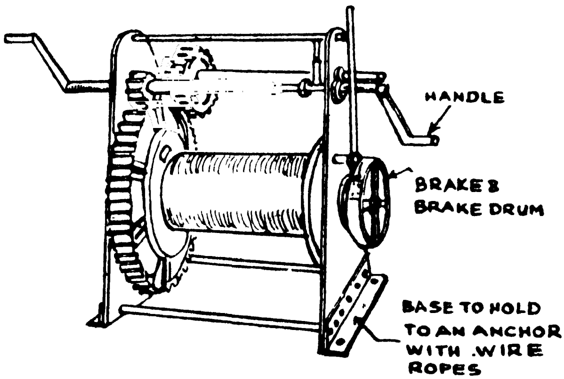


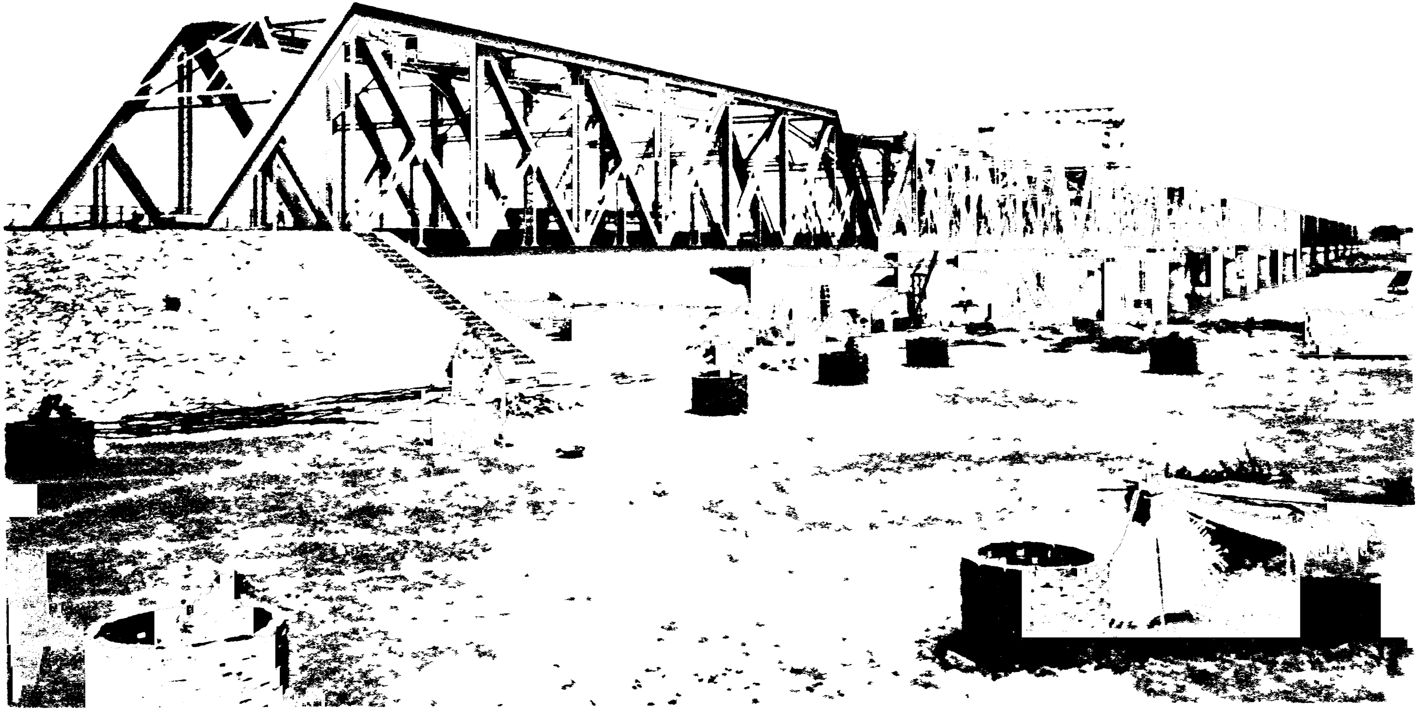
Fig. 2410*b*

A *derrick* is a length of timber or of steel, of suitable section, held vertical and used for lifting heavy loads. It is held in the vertical position with four or more ropes, called *guy ropes.* These ropes are attached to the derrick near its top end and are anchored to suitable anchors on the ground. A pulley block is attached near the top of the derrick and another block is fixed to the load to be lifted or hauled. The rope is reeved through the two pulley blocks and the free end of the rope is taken through a single-sheave guide pulley to the winch. If, in the single-sheave pulley, one of the arms leading to the hook bar is hinged, to enable the rope to be passed over the pulley at any place, it is called a *gin block.* The guys should be tied to the derrick as close as possible to the pulley block on the top of the derrick and the gin block should be kept as close to the foot of the derrick as possible. These

precautions are necessary to prevent bending stresses in the derrick. A 12″×12″ derrick 40′ long in good condition and made of pitch pine can take a load of 25 tons. For each one foot reduction in height, the load may be increased by a ton. Thus a 30′ derrick will take 35 tons, and a 20′ derrick 45 tons. The factor of safety in all cases is 5.

PART 6

Appendices



A modern railway bridge. Spans are over 250′

Appendices

*APPENDIX 1**

Dimensions and properties of some standard Indian rails (B.S.F.F.) and dimensions of a few standard American rails (F.F.)

Designation and normal weight per yard	Unit	Standard Indian rails					Standard American rails						
	lbs	115	90 R	75 R	60 R	50 R	130	110	100	90	75	60	50
1 Height of rail	in	$6\frac{3}{8}$	$5\frac{5}{8}$	5-1/16	$4\frac{1}{2}$	$4\frac{1}{8}$	$6\frac{3}{4}$	$6\frac{1}{4}$	6	$5\frac{5}{8}$	4-13/16	$4\frac{1}{4}$	$3\frac{7}{8}$
2 Width of foot	in	$6\frac{1}{8}$	$5\frac{3}{8}$	4-13/16	4-5/16	3-15 16	6	$5\frac{1}{2}$	$5\frac{3}{8}$	$5\frac{1}{8}$	4-13/16	$4\frac{1}{4}$	$3\frac{7}{8}$
3 Width of head	in	2-15/16	$2\frac{5}{8}$	2-7/16	$2\frac{1}{4}$	2-1 16	2-15 16	2-25/32	2-11/16	2-9/16	2-15/32	$2\frac{3}{8}$	$2\frac{1}{8}$
4 Thickness of web	in	39/64	35/64	33/64	7/16	25/64	21 32	19/32	19 16	9/16	17/32	31/64	7/16
5 Thickness of head at the centre line of rail	in	1-15/16	1-23 32	1-9 16	1-13/32	1-19/64	1-27 32	1-23/32	1-23/32	1-15 32	1-27/64	1-7/32	$1\frac{1}{8}$
6 Thickness of foot at the centre line of rail	in	15/16	13 16	47/64	21/32	19 32	1 7/32	$1\frac{1}{8}$	1	1	27 32	49/64	11/16
7 Diameter of holes for fish-bolts	in	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	1							
8 Moment of inertia about horizontal axis	in^4	62 51	38 45	25 36	16 26	11 44							
9 Moment of inertia about vertical axis	in^4	13 27	7 71	5 53	3 50	2 57							
10 Section modulus (compression)	in^3	18 50	13 05	9 72	7 04	5 43							
11 Section modulus (tension)	in^3	20 90	14 38	10 34	7 44	5 68							
12 Distance of neutral axis from base of rail	in	2 995	2 675	2 453	2 190	2 015							

*Details in Appendix 1, except details of standard American rails, have been collected from publications of the Research Design and Standard Organisation of the Railway Board

APPENDIX 2

Dimensions and properties of standard Indian fishplates

Used with type of rail.	lbs.	115	90R	75R	60R	50R
1. Weight of fishplates (per pair) ..	lbs.	50.79	42.74	30.09	22.46	18.47
2. Length of fishplate .	Ft.&in	1′6″	1′6″	1′4½″	1′4″	1′4″
3. Diameter of hole ..	in.	1-7/32	1-1/16	1-1/16	15/16	13/16
4. Centre to centre of holes	in.	4½	4½	4	4	4
5. End of fishplate to centre of nearest hole	in.	2¼	2¼	2½	2	2
6. Moment of inertia about horizontal axis (per pair) ..	$in.^4$	18.22	11.51	6.93	4.04	2.54
7. Section modulus per pair of fishplates: (for tension) ..	$in.^3$	8.58	6.00	3.95	2.60	1.85
(for compression)..	$in.^3$	8.17	5.97	4.08	2.70	1.86

APPENDIX 3

Dimensions of standard Indian fishbolts and nuts

Used with type of rail.	lbs.	115	90R	75R	60R	50R
1. Weight	lbs.	3.03	2.33	2.33	1.515	1.01
2. Diameter of bolt ..	in.	1⅛	1	1	7/8	3/4
3. Length of shank ..	in.	5-1/4	5	5	4	3½
4. Thickness of head ..	in.	63/64	7/8	7/8	49/64	21/32
5. Thickness of nut ..	in.	1-7/16	1-5/16	1-5/16	1-5/32	1
6. Width between parallel faces of hexagonal nuts ..	in.	1.86	1.67	1.67	1.48	1.30

APPENDIX 4

Indian standard turnouts

Important dimensions

Gauge crossing section of rails	Broad			Metre		
	1 in 8½ 90 R	1 in 12 90 R	1 in 16 90 R	1 in 8½ 60 R	1 in 12 60 R	1 in 16 60 R
1. Overall length of turnout	96′ 9¼	134′ 5⅜	172′ 0 15/16	64′ 5¾	86′ 10	105′ 0½
2. Heel of switch to actual nose of crossing	68′ 4⅝ (68′ 4½ for 75 R)	96′ 4 (96′ 3¾ for 75 R)	122′ 8 1/16	38′ 2¾	53′ 11¾	66′ 4¾
3. Heel of switch to actual toe of switch.	15′ 6	21′	32′	13′ 6	18′	24′ 4
4. Heel of switch to theoretical nose of crossing	68′	95′ 9½	121′ 11 5/16	37′ 11	53′ 6¼	65′ 9¾
5. Heel of switch to theoretical toe of switch	16′ 3 11/16	22′ 17/16	34′ 11	14′ 3	19′ 0⅛	27′ 3
6. Throat to actual nose of crossing ..	3′ 2⅝ (3′ 2½ for 75 R)	4′ 7 (4′ 6¾ for 75 R)	3′ 0 13/16	3′ 3¾	4′ 5¼	2′ 9 1/32
7. Heel divergence	5⅜″	5¼″	5¼″	4¾″	4⅝″	4⅝″
8. Radius of turnout curve	729′	1450′	2704′	392′	789′	1550′
9. Switch angle	1° 34′ 27″	1° 8′ 0″	0° 24′ 27″	1° 35′ 30″	1° 9′ 38″	0° 24′ 27″
10. Crossing angle	6° 42 35″	4° 45′ 49″	3° 34′ 35″	6° 42′ 35″	4° 45′ 49″	3° 34′ 35″

APPENDIX 5

Weight (tons) per mile of rails and fastenings

Section of rail	Length of rail				
	30′	33′	36′	39′	42′
	Weight in tons				
50R	82.1	81.8	81.5	81.3	81.1
60R	98.8	98.4	98.0	97.7	97.5
75R	124.0	123.5	123.0	122.6	122.3
90R	149.6	148.9	148.2	147.7	147.3
115	190.6	189.7	188.9	188.3	187.8

APPENDIX 6

Unit weight of rails, weight per mile and number per ton

	Length of rail:	30 ft.	33 ft.	36 ft.	39 ft.	42 ft.
Rail section	Number per track mile	352.00	320.00	294.00	271.00	252.00
50R	Weight of each (ton)	0.223	C.246	0.268	0.290	0.313
	Weight per traek mile			78.6 tons		
	Number per ton	4.480	4.073	3.733	3.446	3.200
60R	Weight of each (ton)	0.268	0.295	0.321	0.348	0.375
	Weight per track mile			94.3 tons		
	Number per ton	3.734	3.394	3.111	2.872	2.667
75R	Weight of each (ton)	0.335	0.368	0.402	0.435	0.469
	Weight per track mile			117.9 tons		
	Number per ton	2.987	2.715	2.489	2.298	2.133
90R	Weight of each (ton)	0.402	0.442	0.482	0.522	0.563
	Weight per track mile			141.4 tons		
	Number per ton	2.489	2.262	2.074	1.915	1.778
115	Weight of each (ton)	0.513	0.565	0.616	0.667	0.719
	Weight per track mile			180.7 tons		
	Number per ton	1.947	1.771	1.623	1.498	1.391

APPENDIX 7

Fishplates—weight per mile and number per ton

	Length of rail:	30 ft.	33 ft.	36 ft.	39 ft.	42 ft.
	Number per track mile	704.00	640.00	586.67	541.54	502.86
50 R ..	Weight per pair			18.47 lbs.=0.00825 ton		
	Weight per track mile (tons)	2.902	2.639	2.419	2.233	2.073
	Number per ton			242.6		
60 R ..	Weight per pair			22.46 lbs.=0.01002 ton		
	Weight per track mile (tons)	3.529	3.209	2.941	2.715	2.521
	Number per ton			199.5		
75 R ..	Weight per pair			30.09 lbs.=0.01343 ton		
	Weight per track mile (tons)	4.728	4.299	3.940	3.637	3.377
	Number per ton			148.9		
90 R ..	Weight per pair			42.74 lbs.=0.01908 ton		
	Weight per track mile (tons)	6.716	6.106	5.597	5.166	4.797
	Number per ton			104.8		
115 ..	Weight per pair			50.79 lbs.=0.02267 ton		
	Weight per track mile (tons) .	7.981	7.256	6.651	6.139	5.701
	Number per ton			88.2		

APPENDIX 8

Fishbolts—weight per mile and number per ton

	Length of rail	30 ft	33 ft	36 ft	39 ft	42 ft.
	Number per track mile	1408 00	1280 00	1174 00	1084 00	1006 00
50 R	Weight per set of 4			4 04 lbs =0 0018 ton		
	Weight per track mile (tons)	0 635	0 577	0 529	0 488	0 453
	Number per ton			2222 8		
60 R	Weight per set of 4			6 06 lbs =0 00271 ton		
	Weight per track mile (tons)	0 952	0 866	0 797	0 733	0 680
	Number per ton			1478 5		
75 R and 90 R	Weight per set of 4			9 32 lbs =0 00416 ton		
	Weight per track mile (tons)	1 465	1 331	1 220	1 127	1 046
	Number per ton			961 4		
115	Weight per set of 4			12 12 lbs =0 0054 ton		
	Weight per track mile (tons)	1 904	1 731	1 583	1 465	1 360
	Number per ton			739 3		

APPENDIX 9

Weight per track mile of sleepers

Sleepers Standard	Rail length in feet	No of ordinary sleepers		Weight in tons per track mile of sleepers							
				Steel trough sleepers						Cast iron sleepers (CST 9 type)	
				With pressed up lugs			With loose jaws				
				B G		M G	B G		M G	B G	M G
		Per rail length of track	Per track mile	115 90R	75R	60R 50R	115 90R	75R	60R 50R	90R	60R
N	30	10	1760	137 7	127 9	60 5	139 7	129 8	62 0	177 1	99 4
	33	11	1760	137 7	127 9	60 5	139 7	129 8	62 0	177 1	99 4
	36	12	1760	137 7	127 9	60 5	139 7	129 8	62 0	177 1	99 4
	39	13	1760	137 7	127 9	60 5	139 7	129 8	62 0	177 1	99 4
	42	14	1760	137 7	127 9	60 5	139 7	129 8	62 0	177 1	99 4
N + 1	30	11	1936	151 5	140 7	66 5	159 7	142 8	68 1	194 8	109 3
	33	12	1920	150 2	139 5	66 0	152 4	141 7	67 6	193 2	108 4
	36	13	1907	149 2	138 6	65 5	151 4	140 7	67 1	191 9	107 6
	39	14	1896	148 4	137 8	65 1	150 5	139 9	66 7	190 8	107 0
	42	15	1886	147 6	137 1	64 1	149 7	139 1	66 4	189 8	106 5
N + 2	30	12	2112	165 3	153 5	72 5	167 7	155 8	74 3	212 5	119 2
	33	13	2080	162 8	151 2	71 4	165 1	153 4	73 2	209 3	117 4
	36	14	2054	160 7	149 3	70 6	163 1	151 5	72 3	206 7	115 9
	39	15	2031	158 9	147 6	69 8	161 2	149 8	71 5	204 3	114 6
	42	16	2012	157 4	146 2	69 1	159 7	148 4	70 8	202 3	113 6
N + 3	30	13	2288	179 0	166 3	78 6	181 6	168 8	80 5	230 2	129 2
	33	14	2240	175 3	162 8	76 9	177 8	165 3	78 8	225 4	126 4
	36	15	2200	172 2	159 9	75 6	174 6	162 3	77 4	221 3	124 2
	39	16	2168	169 5	157 4	74 4	171 9	159 8	76 2	217 9	122 3
	42	17	2137	167 3	155 4	73 4	169 6	157 7	75 2	215 1	120 6
N + 4	30	14	2464	192 8	179 1	84 6	195 6	181 8	86 7	247 9	139 1
	33	15	2400	187 8	174 4	82 4	190 5	177 1	85 5	241 5	135 5
	36	16	2347	183 7	170 6	80 6	186 3	173 2	82 6	236 1	132 5
	39	17	2302	180 1	167 3	79 1	182 7	169 8	81 0	231 6	129 9
	42	18	2262	177 0	165 1	77 7	179 6	166 1	79 6	227 5	127 7
N + 5	30	15	2640	206 6	191 9	90 7	209 6	194 8	92 9	265 6	149 0
	33	16	2560	200 3	186 0	87 9	203 2	188 9	90 1	257 5	144 5
	36	17	2494	195 2	181 2	85 7	198 0	184 0	88 8	250 3	140 8
	39	18	2437	190 7	177 1	83 7	193 5	179 8	85 8	245 2	137 6
	42	19	2389	186 9	173 6	82 1	189 6	176 3	84 1	240 4	134 9
N + 6	30	16	2816	220 4	204 6	96 7	223 5	207 8	99 1	283 3	159 0
	33	17	2720	212 8	197 7	93 4	215 9	200 7	95 7	273 7	153 5
	36	18	2640	206 6	191 9	90 7	209 6	194 8	92 9	265 6	149 0
	39	19	2572	201 3	186 9	88 3	204 2	189 8	90 5	258 8	145 2
	42	20	2514	196 7	182 7	86 4	199 6	185 5	88 5	252 9	141 9

APPENDIX 10

Radii of various degrees of curves

Degree of curve	Radius in feet	Degree of curve	Radius in feet	Degree of curve	Radius in feet
¼	22918	8¼	695	23½	246
⅓	17189	8½	675	24	241
½	11459	8¾	655	24½	236
⅔	8594	9	637	25	231
¾	7640	9¼	620	25½	227
1	5730	9½	601	26	222
1¼	4584	9¾	588	26½	218
1½	3820	10	573	27	214
1¾	3274	10½	546	27½	210
2	2865	11	522	28	207
2¼	2547	11½	499	28½	203
2½	2292	12	478	29	200
2¾	2084	12½	459	29½	196
3	1910	13	442	30	193
3¼	1763	13½	425	30½	190
3½	1637	14	410	31	187
3¾	1528	14½	396	31½	184
4	1433	15	383	32	181
4¼	1348	15½	371	32½	179
4½	1279	16	359	33	176
4¾	1207	16½	348	33½	174
5	1146	17	338	34	171
5¼	1092	17½	329	34½	169
5½	1042	18	320	35	166
5¾	997	18½	311	35½	164
6	955	19	303	36	162
6¼	917	19½	295	36½	160
6½	882	20	288	37	158
6¾	849	20½	281	37½	156
7	819	21	274	38	154
7¼	791	21½	268	38½	152
7½	764	22	262	39	150
7¾	740	22½	256	39½	146
8	717	23	251	40	143

APPENDIX 11

Superelevation for various speeds and speed limit on curves

Degree of curve	Radius of curve in feet	Maximum permissible speed m. p. h.	Superelevation in inches with average or weighted average speed in miles per hour taken as 60	55	50	45	40	35	30	25	20	15	10	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							BROAD GAUGE							
½	11460	60	1.38	1.16	0.96	0.78	0.61	0.47	0.35	0.24	0.15	0.09	0.04	1. The maximum permissible speed is calculated on the basis of maximum permissible speed on straight track at 60 m.p.h. for B. G., 45 m.p.h. for M. G. and 25 m.p.h. for N.G.
1	5730	60	2.76	2.32	1.92	1.55	1.23	0.94	0.69	0.48	0.31	0.17	0.08	
1½	3820	60	4.15	3.48	2.88	2.33	1.84	1.41	1.04	0.72	0.46	0.26	0.12	
2	2865	60	5.53	4.64	3.84	3.11	2.46	1.88	1.38	0.96	0.61	0.34	0.15	
2½	2293	60	6.5	5.57	4.61	3.73	2.95	2.26	1.66	1.15	0.74	0.42	0.18	2. The maximum superelevation is limited to 6½″ for B.G., 4″ for M.G., and 3″ for N.G. Provided the permissible deficiency in superelevation is not exceeded, reduction in speed is not necessary because of the full theoretical superelevation not being given.
3	1910	60	6.5	6.5	5.76	4.66	3.69	2.82	2.07	1.44	0.92	0.52	0.23	
3½	1637	56.5	—	6.5	6.5	5.44	4.30	3.29	2.42	1.68	1.07	0.60	0.27	
4	1432	52.2	—	—	6.5	6.22	4.91	3.76	2.76	1.92	1.23	0.69	0.31	
5	1146	45.6	—	—	—	6.5	6.14	4.70	3.46	2.40	1.54	0.86	0.38	
6	955	40.7	—	—	—	—	6.5	5.64	4.14	2.88	1.84	1.04	0.46	3. Underlined figures mean that the superelevation theoretically worked out is higher, but the maximum permissible superelevation is given as per remark 2 above.
7	819	36.8	—	—	—	—	—	6.5	4.84	3.36	2.15	1.21	0.54	
8	716	33.5	—	—	—	—	—	—	5.53	3.84	2.46	1.38	0.61	

Degree of curve	Radius of curve in feet	Maximum permissible speed m. p. h.	Superelevation in inches with average or weighted average speed in miles per hour taken as											Remarks
			60	55	50	45	40	35	30	25	20	15	10	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9	637	30.6	—	—	—	—	—	—	6.22	4.32	2.76	1.55	0.69	
10	573	28.2	—	—	—	—	—	—	—	4.80	3.07	1.73	0.77	
METRE GAUGE														
½	11460	45	—	—	—	0.46	0.37	0.28	0.21	0.14	0.09	0.05	0.02	
1	5730	45	—	—	—	0.93	0.73	0.56	0.41	0.29	0.18	0.10	0.05	
1½	3820	45	—	—	—	1.39	1.10	0.84	0.62	0.43	0.27	0.15	0.07	
2	2865	45	—	—	—	1.85	1.46	1.12	0.82	0.57	0.36	0.20	0.09	
3	1910	45	—	—	—	2.78	2.19	1.68	1.23	0.86	0.55	0.31	0.14	
4	1432	45	—	—	—	3.70	2.92	2.24	1.64	1.14	0.73	0.41	0.18	
5	1146	45	—	—	—	4.0	3.66	2.80	2.06	1.43	0.91	0.51	0.23	
6	955	40.7	—	—	—	—	4.0	3.36	2.47	1.71	1.10	0.62	0.27	
7	819	36.8	—	—	—	—	—	3.92	2.88	2.00	1.28	0.72	0.32	
8	716	33.5	—	—	—	—	—	—	3.29	2.29	1.46	0.82	0.37	
9	637	30.6	—	—	—	—	—	—	3.70	2.57	1.65	0.93	0.41	
10	573	28.2	—	—	—	—	—	—	—	2.86	1.83	1.03	0.46	

Degree of curve	Radius of curve in feet	Maximum permissible speed m. p. h.	Superelevation in inches with average or weighted average speed in miles per hour taken as											Remarks
			60	55	50	45	40	35	30	25	20	15	10	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
11	521	26.1	—	—	—	—	—	—	—	3.14	2.01	1.13	0.50	
12	478	24.2	—	—	—	—	—	—	—	—	2.19	1.23	0.55	
13	442	22.4	—	—	—	—	—	—	—	—	2.38	1.34	0.59	
14	410	20.7	—	—	—	—	—	—	—	—	2.56	1.44	0.64	
15	383	19.2	—	—	—	—	—	—	—	—	—	1.54	0.68	
16	359	17.7	—	—	—	—	—	—	—	—	—	1.65	0.73	
NARROW GAUGE														
1	5730	25	—	—	—	—	—	—	(0.31)	0.22	0.14	0.08	0.04	4. Non-transitioned curves have been assumed for N.G.
2	2865	25	—	—	—	—	—	—	(0.63)	0.44	0.28	0.16	0.07	5. If transitioned curves are used the speeds indicated in column 3 are to be increased by 25 per cent. subject to a limit of 30 m.p.h. The speeds for transitioned curves upto 9° may then be taken as 30 m.p.h. The superelevation for this maximum speed of 30 m.p.h. is given in brackets.
3	1910	25	—	—	—	—	—	—	(0.94)	0.65	0.42	0.24	0.10	
4	1432	25	—	—	—	—	—	—	(1.26)	0.87	0.56	0.31	0.14	
5	1146	25	—	—	—	—	—	—	(1.57)	1.09	0 70	0.39	0.17	
6	955	25	—	—	—	—	—	—	(1.88)	1.31	0.84	0.47	0.21	

Degree of curve	Radius of curve in feet	Maximum permissible speed m.p.h	Superelevation in inches with average or weighted average speed in miles per hour taken as											Remarks
			60	55	50	45	40	35	30	25	20	15	10	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7	819	25	—	—	—	—	—	—	(2.20)	1.53	0.98	0.55	0.24	
8	716	25	—	—	—	—	—	—	(2.51)	1.74	1.12	0.63	0.28	
9	637	24.8	—	—	—	—	—	—	(2.83)	—	1.26	0.71	0.31	
10	573	23.5	—	—	—	—	—	—	—	—	1.40	0.79	0.35	
12	478	21.4	—	—	—	—	—	—	—	—	1.68	0.94	0.42	
14	409	19.7	—	—	—	—	—	—	—	—	—	1.10	0.49	
16	358	18.4	—	—	—	—	—	—	—	—	—	1.26	0.56	
18	318	17.3	—	—	—	—	—	—	—	—	—	1.41	0.63	
20	287	16.4	—	—	—	—	—	—	—	—	—	1.57	0.70	
30	191	13.2	—	—	—	—	—	—	—	—	—	—	1.05	
40	143	11.2	—	—	—	—	—	—	—	—	—	—	1.40	

APPENDIX 12

A selection from the Indian standard dimensions

Serial No.	Item	B.G. (5′-6″)		M.G. (3′-3⅜″)		N.G. (2′-6″)		Remarks
		Permissible	Recommended	Permissible	Recommended	Permissible	Recommended	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Minimum distance centre to centre of track							1. (i) Extra clearances required on curves are given in item 23.
	(*a*) outside station yards .	14′-0″		12′-0″		11′-6″	12′-0″ and 14′-0″	(ii) The minimum distance between tracks on through and semi-through girders and in tunnels is 14′-9″ and the minimum recommended distance is 15′-6″ for B.G.
	(*b*) in station yards where water column, signal post etc. are likely between tracks ..	14′-0″	15′-6″	12′-6″ and 14′-0″	14′ and 14′-6″	12′-6″ and 13′-6″	14′-0″	
	(*c*) in running sheds ..		17′-3″		15′-0″		15′-0″	(iii) The dimensions 14′-0″ in column 5, 14′-6″ in column 6 and 13′-6″ in column 7 apply when one of the two adjacent tracks is a passenger track.
2	Width of bank							
	(*a*) single line		20′-0″		16′-0″		12′-0″	(iv) The figures 14′-0″, 14′-0″ and 15′-0″ in column 8 permit future conversion to B.G.
	(*b*) double line		35′-0″		28′-0″		24′-0″	
3	Width of cutting excluding side drains							2 and 3 For Standard C lines, items 2*a* and 3*a* are reduced to 16′-6″ for B.G. and 2*b* and 3*b* to 32′-0″. A reduction of 2′-0″ is made in items 2*a*, 2*b*, 3*a* and 3*b* for M.G. standard C lines.
	(*a*) single line		18′-0″		14′-0″		11′-0″	
	(*b*) double line		33′-0″		26′-0″		23′-0″	
4	Maximum degree of curve ..	10°		16°		40°		

Serial No.	Item	B.G. (5′-6″)		M.G. (3′-3⅜″)		N.G. (2′-6″)		Remarks
		Permissible	Recommended	Permissible	Recommended	Permissible	Recommended	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
5	Ballast section							
	(a) width at level of foot of rail		11′-0″		7′-6″		6′-0″	
	(b) depth below sleeper ..		0′-8″		0′-8″		0′-6″	
6	Minimum height above rail level for overhead structures							6. Where electric traction exists or is likely, the minimum height should be 17′-9″ for B.G. and 13′-9″ for M.G.
	(a) outside station yards..	16′-0″		12′-6″		12′-6″		
	(b) within station yards for foot bridges or signal gantries	16′-0″		14′-6″		14′-6″		
	(c) within station yards for any part of a covering structure	20′-0″		18′-0″		16′-0″		
7	Minimum horizontal distance from the centre of track to any structure from 1′-0″ above rail level	7′-0″		6′-3″		6′-0″		7. (i) These dimensions do not apply to platforms. (ii) The minimum distance to a telegraph post should be the height to the post plus the clearances given in item 7, unless properly guyed, in which case,

								clearances given in item 7 are sufficient. (iii) Extra clearances required on curves are given in item 23. (iv) For N.G., the minimum distance is required from 0′-9″ above rail level.
8	Maximum gradient in station yards	1 in 400	1 in 1000	1 in 400	1 in 1000	1 in 400	1 in 1000	
9	Exact distance from centre of track to face of passenger platform coping	5′-6″		4′-5″		4′-0″		
10	Height above rail level for platforms							
	(*a*) high passenger platform	2′-6″ min. 2′-9″ max.		1′-0″ min. 1′-4″ max.		0′-9″ min. 1′-4″ max.		
	(*b*) low passenger platform	1′-6″		—		—		
	(*c*) goods platform ..	3′-6″		2′-3″		2′-0″		
11	Minimum horizontal distance from the centre line of track to							11. (i) These dimensions are applicable from 1′ above platform level to heights varying from 11′-3″ to 13′-0½″ above rail level for B.G.; 9′-9″ to 10′-6″ for M.G.; and 9′-6″ for N.G. (ii) The figure 18′-3″ applies to island platforms.
	a) any building on a passenger platform ..	17′-6″	23′-6″	16′-5″	22′-5″	16′-0″	18′-3″	
	(*b*) any building on a goods platform ..	15′-6″		10′-5″		10′-0″		

Serial No.	Item	B.G. (5′-6″)		M.G. (3′-3⅜″)		N.G. (2′-6″)		Remarks
		Permissible	Recommended	Permissible	Recommended	Permissible	Recommended	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(c) a pillar, column, lamp or similar isolated structure on a passenger platform	15′-6″		10′-5″		10′-0″		
	(d) a pillar, column, lamp or similar isolated structure on a goods platform	13′-6″		10′-5″		10′-0″		
12	Minimum length of tongue rail	12′		9′-0″		7′		
13	Maximum width over open doors including all projections							
	(a) for passenger vehicles.	13′-3″		12′-6″		11′-6″		
	(b) for goods vehicles ..	14′-0″		12′-6″		11′-6″		

14	Maximum width of loading gauge for goods vehicles ..	10′-8″		8′-8″		7′-8″		
15	Maximum height of loading gauge for goods vehicles above rail level							
	(*a*) at centre	13′-7″		11′-4″		10′-7″		
	(*b*) at sides	11′-7″		10′-7″		9′-7″		
16	Maximum rigid wheel base for four-wheeled vehicles	20′-0″		12′-0″ 16′-0″		12′-0″ 10′-0″ 8′-0″ and 6′-3″		16. (i) 12′-0″ rigid wheel base is used on M.G. where curves are sharper than 10°. (ii) Rigid wheel bases on N.G. are as follows :— 12′-0″ where the sharpest curve is 10° 10′-0″ ,, 16° 8′-0″ ,, 30° 6′-3″ over 30°
17	Maximum length of body or roof for							
	(*a*) Bogie vehicles ..	68′-0″		64′-0″		45′-0″		
	(*b*) Four-wheeled vehicles.	28′-0″		28′-0″				

Serial No.	Item	B.G. (5′-6″)		M.G. (3′-3⅜″)		N.G. (2′-6″)		Remarks
		Permissible	Recommended	Permissible	Recommended	Permissible	Recommended	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
18	Maximum and minimum wheel gauge or distance apart for all wheel flanges..	5′-3″		3′-0⅝″		2′-3¼″		
19	Maximum distance apart of trolly refuges							
	(*a*) on bridges with main spans of less than 300′.		300′-0″					
	(*b*) on bridges with main spans of 300′ or more		every pier					
20	Size of wooden sleepers							
	(*a*) length		9′-0″		6′-0″			
	(*b*) breadth		0′-10″		0′-8″			
	(*c*) depth		0′-5″		0′-4½″			

21	Maximum axle loads (in tons) for unrestricted speed on different sections of rails :							21. (i) For the axle loads indicated, the rails should not have lost more than 5% of their original section by wear or corrosion for B.G. and M.G. and 10% for N.G. (ii) The axle loads indicated for M.G. are for a maximum speed of 45 m.p.h.
	Section of rail 115 lbs. ..		28.0					
	,, ,, ,, 100 ,, ..		25.0					
	,, ,, ,, 90 ,, ..		22.5					
	,, ,, ,, 85 ,, ..		20.5					
	,, ,, ,, 80 ,, ..		18.5					
	,, ,, ,, 75 ,, ..		17.0					
	,, ,, ,, 70 ,, ..		15.75		17·0			
	,, ,, ,, 65 ,, ..		14.5		15·5			
	,, ,, ,, 60 ,, ..		13.5		14·0		12.0	
	,, ,, ,, 55 , ..				13·0		—	
	,, ,, ,, 50 ,, ..				11.5		11.0	
	,, ,, ,, 45 ,, ..				10.5		9.5	
	,, ,, ,, 40 ,, ..				9.0		8.5	
	,, ,, ,, 35 ,, ..				8.0		7.0	
	,, ,, ,, 30 ,, ..						5.5	
	,, ,, ,, 25 ,, ..						4.5	
	,, ,, ,, 20 ,, ..						3.5	
22	Minimum number of cross sleepers per rail for different axle loads :							22. "*n*" is the length of the rail in yards.
	Axle load in tons	28	*n*+5					
		25	*n*+4					
		22.5	*n*+3					
		18.5	*n*+2		*n*+10			
		17	*n*+1		*n*+ 5			
		13						
		12					*n*+4	
		11			*n*+ 2			
		10					*n*+3	
		9			*n*+ 1			
		7					*n*+2	
		5					*n*+1	

(1)	(2)	Degree of curve (3)	Radius of curve in feet (4)	Extra clearance in inches between tracks (5)	Extra clearance in inches between the track and adjacent structure: Outside of curve (6)	Inside of curve: Upto 2′-9″ above rail level (7)	Inside of curve: From 2′-9″ to 14′-6″ above rail level (8)	Inside of curve: At 17′-9″ above rail level (9)	Remarks (10)
23	Extra clearances on curves								
		BROAD GAUGE							
		1	5730	4	—	0.5	8	10	1. The clearances given in column 1 apply also to 3′-6″ high B.G. goods platforms not located on running lines.
		$1\frac{1}{2}$	3820	6	—	1.5	14	17	
		2	2865	7	0.5	2.0	14	17	2. The figures in column 5 for the clearance between tracks, apply when there are no structures between the tracks. In case of existence of structures, figures in columns 6, 7, 8 and 9 apply.
		3	1910	8	1.0	2.5	15	18	
		4	1432	10	1.5	3.0	16	19	
		5	1146	11	2.0	4.0	16	19	3. For heights between 14′-6″ and 17′-9″, add 1″ per foot of height in column 8.

6	955	12	2.5	4.5	17	20
7	819	13	3.5	5.0	17	20
8	716	14	4.0	5.5	18	21
9	637	16	4.5	6.0	19	22
10	573	17	5.0	7.0	19	22
METRE GAUGE						
			Outside of curve	Inside of curve		
				Upto 1′-4″ above rail level	From 1′-4″ to 10′-6″ above rail level	
1	5730	2.5	—	—	2.5	
2	2865	4.5	—	1.0	5.5	
3	1910	6.5	0.5	1.5	8.5	
4	1432	8.5	1.0	2.5	12.0	
5	1146	10.0	1.5	3.0	13.0	
6	955	11.0	2.0	3.5	13.5	
7	819	12.0	3.0	4.0	13.5	
8	716	13.0	3.5	4.5	14.0	
9	637	14.0	4.0	5.0	14.0	
10	573	15.0	4.5	5.5	14.5	
11	521	15.5	5.0	6.0	14.5	
12	477	16.5	5.5	6.5	15.0	
13	441	17.5	6.0	7.0	15.0	
14	409	18.5	6.5	7.5	15.0	
15	382	19.5	7.0	8.0	15.5	
16	358	20.5	7.5	8.5	15.5	

4. The clearances given in column 7 apply also to 2′-3″ high M.G. goods platforms not located on running lines.

5. For any heights above 10′-6″, add 1″ per foot of height to the figures given in column 8.

Serial No.	Item	Degree of curve	Radius of curve in feet	Extra clearance in inches between tracks	Extra clearance in inches between the track and adjacent structure				Remarks
					Outside of curve	Inside of curve			
						Upto 2′-9″ above rail level	From 2′-9″ to 14′-6″ above rail level	At 17′-9″ above rail level	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		NARROW GAUGE							
					Outside of curve	Inside of curve			
						Upto 0′-9″ above rail level	Upto 2′-0″ above rail level	Any height from 2′-0″ above rail level	
		1	5730	3	2	0	1	2	
		2	2865	4	3	1	1	4	
		3	1910	5	3	1	2	6	
		4	1432	6	3	2	3	8	
		5	1146	8	3	2	3	10	
		6	955	9	3	3	4	12	
		7	819	10	4	3	5	14	
		8	716	11	4	4	5	16	
		9	637	12	4	4	6	18	
		10	573	13	4	4	7	20	
		12	477	14	5	5	7	21	
		14	409	15	5	6	8	21	
		16	358	16	6	6	8	22	
		18	318	17	6	7	9	23	
		20	286	18	7	7	10	23	
		30	191	24	9	10	13	26	
		40	143	29	11	13	16	29	

APPENDIX 13

Railway gauges in various countries

Broad Gauge

(*1*) 5′-6″—India, Pakistan, Ceylon, Argentine, Brazil, Chile.

(*2*) 5′-5¾″—Spain, Portugal.

(*3*) 5′-3″—Australia, Eire.

(*4*) 5′-0″—U.S.S.R.

Standard Gauge

(*1*) 4′-8½″—Britain, U.S.A., Canada, Australia, China, Egypt.

(*2*) 4′-9⅛″—(1.45 metres)—Europe (except Britain, Eire, U.S.S.R., Spain and Portugal).

Metre Gauge

Note.—The 3′-6″ gauge is given under this head for convenience.

(*1*) 3′-6″—South Africa, Australia, New Zealand, Japan.

(*2*) 3′-3⅜″—(1 metre),—India, Burma, Malaya, Siam, some countries in Europe, e.g. France.

Narrow Gauge

(*1*) 2′-6″—India, Chile.

(*2*) 2′-0″—India, South Africa.

APPENDIX 14

Maintenance programme

Item of work	October	November	December	January	February	March	April	May	June	July	August	September
Renewal of sleepers ..												
Oiling clip bolts of steel trough sleepers.												
Through screening of ballast												
Through packing and dressing												
Cutting and cleaning drains												
Lubricating fishbolts and fishplates ..												
Slacks and miscellaneous works	.. ..	.. ..	.. ..	.. ..	As R	equir	ed ..	.. ..	.. ..	..		

Note :— 1. This programme permits of 2 days per week being allotted to slacks and miscellaneous works, if required between October and July.

2. Renewals of sleepers and oiling of clip bolts commences immediately the rains cease. Maximum time allotted for these works is 2 months.

3. The clip bolts of steel sleepers of half the gang length are oiled annually, i.e. each clip bolt is oiled once in two years. The work is done by the whole gang and care is taken to see that the gauge is not disturbed.

4. Screening of ballast commences immediately after the renewal of sleepers and the oiling of clip bolts. Minimum of 1 mile is done each year.

5. Through packing and dressing is commenced not later than 1st February.

6. Lubricating fishbolts and fishplates is done in the season shown above, by two gangs working together and with the work properly protected. This work is not to be done in more than two places at a time on each P.W.Is. and S.P.W.Is.

APPENDIX 15 (1)

Realignment of curves

Proof of the statement that "throw equals twice the moment of differences of versines"

In para 1313*d* it was proved that the throw of a point D, with respect to a semi-chord AB, is 2 $(a_2 + 2a_1)$ where a_1 and a_2 are versines at B and C (*vide* Fig. 1313*e*). If stations are numbered 0, 1, 2, 3, 4, etc. the throw at station 3 is equal to $(a_2 + 2a_1)$. Similarly the throw at stations 5 is 2 $(a_4 + 2a_3 + 3a_2 + 4a_1)$, where a_1, a_2, a_3 and a_4 are the versines at stations 1, 2, 3 and 4. Let a_1, a_2, a_3 and a_4 be the ideal versines, then the throw at station 5 of the ideal versines is as above.

If a_1', a_2', a_3', a_4' are the existing versines at the same stations the throw at station 5 of the existing versines is 2 $(a_4' + 2a_3' + 3a_2' + 4a_1')$. Again if $a_1 - a_1' = a_1''$, $a_2 - a_2' = a_2''$ etc., if a_1'', a'', a_3'' and a_4'' are the differences between the ideal and existing versines, the difference in throws, namely the shift at station 5 between the ideal and the existing versines, is 2 $(a_4'' + 2a_3'' + 3a_2'' + 4a_1'')$. Double summation of the difference between the ideal and the existing versines gives the following results.

Station No.	Difference between ideal and existing versines	Sum of the differences of versines	Moment (or sum of the previous column) i.e. Moment of differences of versines
1	2	3	4
0	0	0	
1	a_1''	a_1''	0
2	a_2''	$a_1''+a_2''$	a_1''
3	a_3''	$a_1''+a_2''+a_3'$	$2al''+a_2''$
4	a_4''	$a_1''+a_2''+a_3''+a_4''$	$3al''+2a_2''+a_3''$
5			$4a_1''+3a_2''+2a_3''+a_4'$

The throw at station 5 is, therefore, 2 $(4a_1'' + 3a_2'' + 2a_3'' + a_4'')$ which is the same as that worked out above from the formula given in para 1313*d*. It will be noted that the last column gives the moment of the difference of versines. Another important point to be noted is that the value in the column *Sum* is written between

stations. The values in column *Moment* is written opposite the station number, but one station lower than the station against which the versine difference is given. The reason is that the throw at station, say 3, is affected by the versines at stations 1 and 2, the throw at station 4 is affected by the versines at stations 1, 2 and 3 and so on.

APPENDIX 15(2)

Realignment of curves—sums and moments of equal and equally increasing amounts

TABLE I

Station No.	Alteration in versines										Sum of differences in versines										Moments of differences in versines									
	a	b	c	d	e	f	g	h	i	j	a	b	c	d	e	f	g	h	i	j	a	b	c	d	e	f	g	h	i	j
(1)	(2)										(3)										(4)									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
2		1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1
3			1	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3
4				1	1	1	1	1	1	1	1	2	3	4	4	4	4	4	4	4	3	5	6	6	6	6	6	6	6	6
5					1	1	1	1	1	1	1	2	3	4	5	5	5	5	5	5	4	7	9	10	10	10	10	10	10	10
6						1	1	1	1	1	1	2	3	4	5	6	6	6	6	6	5	9	12	14	15	15	15	15	15	15
7							1	1	1	1	1	2	3	4	5	6	7	7	7	7	6	11	15	18	20	21	21	21	21	21
8								1	1	1	1	2	3	4	5	6	7	8	8	8	7	13	18	22	25	27	28	28	28	28
9									1	1	1	2	3	4	5	6	7	8	9	9	8	15	21	26	30	33	35	36	36	36
10										1	1	2	3	4	5	6	7	8	9	10	9	17	24	30	35	39	42	44	45	45

APPENDIX (15) 2—(Contd.)

TABLE II

Station No.	Difference in versines			Sum of differences in versines			Moments of differences in versines		
	l	m	n	l	m	n	l	m	n
0				0	0	0	0	0	0
1	+1		+1	1	0	1	0	0	0
2				1	0	1	1	0	1
3		+1		1	1	1	2	0	2
4			+1	1	1	2	3	1	3
5				1	1	1	4	2	5
6				1	1	2	5	3	7
7				1	1	2	6	4	9
8			—1	1	1	1	7	5	11
9	—1		—1	0	1	0	8	6	12
10				0	1	0	8	7	12
11		—1		0	0	0	8	8	12
12				0	0	0	8	8	12

APPENDIX 15 (3)

Realignment of curves — Example

Station	Existing versines	Revised versines 1st	Revised versines 2nd	Difference 1st	Difference 2nd	Sum 1st	Sum 2nd	Moment 1st	Moment 2nd	Slew	Distance of peg from running edge of outer rail	Super-elevation	Clearances after slewing
0	0	0	0	0	0	0	0				2′-9″	0	
1	31	0	0	31	31	31	31	0	0	0	2′-9″	0	
2	50	0	0	50	50	81	81	31	31	.62	2′-8.38″	0	
3	38	0	0	38	38	119	119	112	112	2.24	2′-6.76″	0	Blast wall 7′-0½″
4	150	100+20	120	50	30	169	149	231	231	4.62	2′-4.38″	.8	
5	250	200+20+20	240	50	10	219	159	400	380	7.60	2′-1.40″	1.7	Blast wall 7′-0⅞″
6	281	300+20+20+20	360	—19	—79	200	80	619	539	10.78	1′-10.22″	2.6	Gantry post 8′-5½″
7	319	348+20+20+12	400	—29	—81	171	—1	819	619	12.38	1′-8.62″	3.5	
8	431	348+20+20+12	400	83	31	254	30	990	618	12.36	1′-8.64″	3.5	
9	356	348+20+20+12	400	8	—44	262	—14	1244	648	12.96	1′-8.04″	3.5	
10	319	348+20+20+12	400	—29	—81	233	—95	1506	634	12.68	1′-8.32″	3.5	
11	356	348+12—10+23	373	8	—17	241	—89	1739	539	10.78	1′-10.22″	3.15	
12	350	349+4+2	355	1	—3	242	—88	1780	427	8.54	2′-0.46″	2.80	Gantry post 8′-2″
13	369	348—20+10—4	334	21	35	263	—57	2022	310	6.20	2′-2.80″	2.45	
14	338	348—20—20	308	—10	30	253	—27	2285	228	4.56	2′-4.44″	2.10	
15	312	348—20—20—12	296	—36	16	217	—11	2538	176	3.52	2′-5.48″	1.75	
16	294	348—20—20—20—12	276	—54	18	163	7	2755	140	2.80	2′-6.20″	1.40	
17	200	300—20—20—12	248	—100	—48	63	—41	2918	122	2.44	2′-6.56″	1.05	
18	169	200—20—20—12—2	146	—38	14	25	—27	2981	56	1.16	2′-7.84″	0.70	
19	69	100—20—20—12—23	25	—31	44	—6	—6	3006	6	.12	2′-8.88″	0.35	Gantry post 8′-1½″
20	6	0	0	6	6	0	0	3000	0	0	2′-9″	0	Platform ramp 5′-6″
Total	4681	4681	4681										

Notes :—

1. Change in versine per station not to exceed $\frac{6c^3}{s^3} = \frac{6 \cdot 31^3}{66^3} = 0.62$ i.e. 62 units, $S = 66$ since speed is limited to 45 m.p.h.

2. With a 4° curve, permissible speed $= 1.5\sqrt{1433\text{-}220} = 52.2$ miles per hour. Due to other reasons, speed is restricted to 45 miles per hour. With this speed, superelevation$= \frac{4.4 \times 45^2}{1433} = 6.2$ inches. Allowing 3″ permissible deficiency in station yards, superelevation required = 3.2 inches and actually provided = 3½ inches.

APPENDIX 16 (1)

Standard Loadings

(For design purposes)

BROAD GAUGE				
MAIN LINE: (B.G. M.L.)		83′-8¼″	83′-8¼″	
	Axle Loads (Tons)	11 22½ 22½ 22½ 22½ 19 19¼ 19¼ 19¼ 19¼	Same loading as on left	2.3 Tons/Ft.
	Spacings	5′ 9′-2″ 6′-0⅜″ 5′-7¼″ 5′-7¼″ 10 10′-11″ 6′ 8′-6″ 6 5′-5″		
BRANCH LINE. (B.G. B.L.)		75′-4″	75′-4″	
	Axle Loads (Tons)	9 17 17 17 17 16 14⅝ 14⅝ 14⅝ 14⅝	Ditto	1.5 Tons/Ft.
	Spacings	5′ 9 6′-0½″ 5′-7¼″ 5′-7¼″ 8′-9″ 12′-9″ 6 6 6 4′-7″		
METRE GAUGE				
MAIN LINE: (M.G. M.L.)		63′-7″	63′-7″	
	Axle Loads (Tons)	8 13 13 13 13 11.35 11.9 11.9 11.9 11.9	Ditto	1.16 Tons/Ft.
	Spacings	5′-10″ 7′-2½″ 4′-7″ 4′-5″ 4′-5″ 7 8′-9″ 4′-6″ 7′-6 4′-6″ 4′-10″		
BRANCH LINE (M.G. B.L.)		60	60′	
	Axle Loads (Tons)	6.45 10.5 10.5 10.5 10.5 9.2 9.6 9.6 9.6 9.6	Ditto	1.16 Tons/Ft.
	Spacings	5′-10 7′-2½ 4′-7 4′-5 4′-5 6 9′-2½ 4′-6 4′-6 4′-6 4′-10		

APPENDIX 16 (2)

Loadings of Standard Locomotives

PASSENGER

Broad Gauge W P	Total wheelbase	78 -7¾"
	Axle Loads (Tons)	25 9, 18 5, 18 5, 18 5, 16 2, 17 23, 16 79, 19 02, 19 37
	Spacings	5 -3", 8, 6, 6 -1½", 6 -1½", 10, 9 -6", 7, 8 -6", 7', 5'-1¾"
Metre Gauge Y G	Total wheelbase	62 -9¼"
	Axle Loads (Tons)	15 6, 10 5, 10 5, 10 5, 9 95, $\underbrace{19\ 5}$, $\underbrace{19\ 5}$
	Spacings	4 -7⅛", 6 -3", 4 -10", 5, 5, 8 -8, 8 -10", 5, 5, 5', 4'-7⅛"

GOODS

Broad Gauge W G	Total wheelbase	78 -7¾"
	Axle Loads (Tons)	10 28, 17 89, 17 89, 18 15, 18 15, 14 84, $\underbrace{36}$, $\underbrace{36}$
	Spacings	5 -3", 9 -2, 5 -6½", 5 -6½", 6, 10, 9 -6, 7', 8 -6", 7, 5 -1¾"
Metre Gauge Y G	Total wheelbase	62 -9¼"
	Axle Loads (Tons)	6 1, 10 45, 10 45, 10 5, 10 5, 9 0, $\underbrace{19\ 5}$, $\underbrace{19\ 5}$
	Spacings	4 -7⅛", 7 -4", 4 -6", 4 -6", 4 -11", 8 -6", 8 -10", 5, 5', 5, 4'-7⅛"

APPENDIX 16 (3)

Characteristics of Standard Locomotives

	BROAD GAUGE		METRE GAUGE	
	W. P. (Passenger)	W. G. (Goods)	Y. P. (Passenger)	Y. G. (Goods)
1. Overall weight in working order (in tons)	169.9	170.2	96.1	96.0
2. Overall length over buffers	78′-7¾″	78′-7¾″	62′-9¼″	62′-9¼″
3. Overall wheelbase	68′-3″	68′-3″	29′-9″	29′-9″
4. Maximum designed speed (m.p.h.)	65	50	45	40
5. Designed load behind drawbar (tons)	400	1600	260	850
6. Effective tractive effort as limited by adhesion (lbs.)	24864	33152	14112	18816
7. Rated Indicated Horsepower	1640 and 1465	1485 and 1330	1032	947
8. Coal capacity (tons)	15	18	9½	9½
9. Water capacity (gals.)	5500	5000	3000	3000

APPENDIX 17

Useful formulae and data

1. Circumference of a circle $=2\pi$ or πd.
2. Length of arc subtending an angle x° at the centre of a circle of radius r

$$= r\frac{x}{57.3}$$

3. The area of a triangle, with height h perpendicular to any side $a = \frac{1}{2}ah$.
4. The area of a parallelogram, with h as the perpendicular distance between any parallel sides $a = ah$.
5. The area of a trapezium, with h as the perpendicular distance between the two parallel sides, a and b

$$= \tfrac{1}{2}(a+b)\,h.$$

6. The area of a circle $= \pi r^2$ or $\frac{\pi d^2}{4}$ where r = radius and d = diameter.
7. Area of sector on arc $= \frac{r^2}{2} \times \frac{x}{57.3}$ where r = radius, x = angle at the centre subtended by the arc.
8. Area of a parabola $= 2/3$ height $\times$ base.
9. Volume of a cylinder of radius r and height $h = \pi r^2 h$.
10. Volume of a sphere of radius $r = 4/3\,\pi r^3$
11. Volume of pyramid of height h and each side of base $l = \frac{hl^2}{3}$
12. Volume of cone of height h and radius of base r $\frac{\pi r^2 h}{3}$
13. The value of x in the formula $ax^2 + bx + c \quad o$ is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

14. A radian is an angle subtended at the centre of any circle equal in length to the radius.

$$\pi \text{ radius} = 180^\circ$$

$$1 \text{ radian} = \frac{180^\circ}{\pi} = 57.3^\circ$$

15. Value of $\pi = 3.14159265$ or approximately 3.14 or 22/7.

16. Acceleration due to gravity $= 32.2$

17. One mile $= 1.609$ k.m.

One metre $= 3.28084$ feet, say, 3.28 feet.

One foot $= 30.48$ c.m.

One inch $= 25.4$ m.m., say 25 m.m.

18. Trigonometrical functions of angle a in a right angled triangle whose base is AB, vertical CB, hypotenuse AC with angle ABC as the right angle.

sine a (written in short sin a) $= \frac{BC}{AC}$

cosine a (,, ,, cos a) $= \frac{AB}{AC}$

tangent a (,, ,, tan a) $= \frac{BC}{AB}$

contangent a (,, ,, cot a) $= \frac{AB}{BC} = \frac{1}{\tan a}$

secant a (,, ,, sec a) $= \frac{AC}{AB} = \frac{1}{\cos a}$

cosecant a (,, ,, cosec a) $= \frac{AC}{BC} = \frac{1}{\sin a}$

19. Trigonometrical Formulæ

(*a*) $\frac{\sin a}{\cos a} = \tan a.$

(*b*) $\sec^2 a = 1 + \tan^2 a$

(*c*) $\text{cosec}^2 a = 1 + \cot^2 a$

(*d*) $\sin^2 a + \cos^2 a = 1.$

(*e*) $\sin (a + b) = \sin a \cos b + \cos a \sin b$

(*f*) $\sin (a - b) = \sin a \cos b - \cos a \sin b$

(*g*) $\cos (a + b) = \cos a \cos b - \sin a \sin b$

(*h*) $\cos (a + b) = \cos a \cos b + \sin a \sin b$

(*i*) $\tan (a + b) = \frac{\tan a + \tan b}{1 - \tan a \tan b}$

(*j*) $\tan (a - b) = \dfrac{\tan a - \tan b}{1 + \tan a \tan b}$

(*k*) $\sin a + \sin b = 2 \sin \dfrac{a+b}{2} \cos \dfrac{a-b}{2}$

(*l*) $\sin a - \sin b = 2 \cos \dfrac{a+b}{2} \sin \dfrac{a-b}{2}$

(*m*) $\cos a + \cos b = 2 \cos \dfrac{a+b}{2} \cos \dfrac{a-b}{2}$

(*n*) $\cos a - \cos b = 2 \sin \dfrac{a+b}{2} \sin \dfrac{a-b}{2}$

(*o*) $\sin (a + b) + \sin (a - b) = 2 \sin a \cos b$

(*p*) $\sin (a + b) - \sin (a - b) = 2 \cos a \sin b$

(*q*) $\cos (a + b) + \cos (a - b) = 2 \cos a \cos b$

(*r*) $\cos (a - b) - \cos (a + b) = 2 \sin a \sin b$

(*s*) $\sin 2a = 2 \sin a \cos a$

(*t*) $\cos 2a = \cos^2 a - \sin^2 a$, or $1 - 2 \sin^2 a$

(*u*) $\sin^2 a = \frac{1}{2} (1 - \cos 2a)$

(*v*) $\cos^2 a = \frac{1}{2} (1 + \cos 2a)$

(*w*) values of trigonometrical ratios

angle	sin	cos	tan
0°	0	1	0
30°	$\frac{1}{2}$	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{3}}$
45°	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	1
60°	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{1}{\sqrt{3}}$
90°	1	0	∞

20. Work done $= f\,l$ where $f =$ force and $l =$ displacement or the distance through which it acts.

21. Displacement $l = vt$ or $\frac{1}{2} ft^2$ where
$v =$ velocity, $f =$ acceleration, $t =$ time

22. Weight of a cubic foot of water = 62.4 pounds

Weight of a gallon of water = 10 pounds

Number of gallons of water per cubic foot = 6.24

23. 1 ton = 20 cwts. = 80 qrs. = 2240 lbs.

24. 1 mile = 8 furlongs = 1760 yards = 5280 feet

25. 1 acre = 4840 sq. yards = 43560 sq. feet

26. 1 gallon = 4 quarts = 8 pints

27. 1 gross = 12 dozen = 144 numbers

28. 1 ream = 20 quires = 480 sheets

29. Conversion of speed in miles per hour to feet per second

Miles per hour ..	5	10	15	20	25	30	35
Feet per second ..	7.3	14.7	22	29.3	36.7	44	51.3
Miles per hour ..	40	45	50	55	60	65	70
Feet per second .	58.7	66	73.3	80.7	88	95.3	102.7

30. Diameters of standard wire gauge

S.W.G. No.	0	1	2	3	4	5	6
Diameter ..	.324	.300	.276	.252	.232	.212	.192
Dia. to the nearest 1/64 of an inch ..	$\frac{21}{64}$	$\frac{19}{64}$	$\frac{9}{32}$	$\frac{1}{4}$	$\frac{15}{64}$	$\frac{7}{32}$	$\frac{3}{16}$
S.W.G. No.	7	8	9	10	11	12	13
Diameter ..	.176	.160	.144	.128	.116	.104	.092
Dia. to the nearest 1/64 of an inch ..	$\frac{11}{64}$	$\frac{5}{32}$	$\frac{9}{64}$	$\frac{1}{8}$	$\frac{7}{64}$	$\frac{7}{64}$	$\frac{3}{32}$

S.W.G. No.	14	15	16	17	18	19
Diameter ..	.080	.072	.064	.056	.048	.040
Dia. to the nearest 1/64 of an inch ..	$\frac{5}{64}$	$\frac{5}{64}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{64}$	$\frac{3}{64}$

S.W.G. No.	20	25
Diameter ..	.036	.020
Dia. to the nearest 1/64 of an inch ..	$\frac{1}{32}$	$\frac{1}{64}$

31. 1 ton = 1.016 metric tons

    1 kilogram = 2.205 pounds

    1 ounce = 28.35 grams

32. 1 sq. yard = 0.836 m^2

    1 sq. foot = 0.093 m^2

    1 sq. mile = 259 hectares

    1 acre = 40.47 ares

33. 1 gallon = .0045 m^3 = 4.546 litres

    1 cub. yard = .765 m^3

    1 cub. in. = 16.39 cm^3

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